To U.S. Environmental Protection Agency (EPA)

Subject: San Jacinto River Waste Pits Superfund Site – Partial Interim Comments on Draft Feasibility Study

Dear Gary,

Thank you for asking the Technical Review Team of Harris County ("Technical Review Team") to review and provide comments on the Draft Feasibility Study ("Draft FS") prepared by responsible parties McGinnes Industrial Maintenance Corporation and International Paper Company and their consultant Anchor QEA in connection with the San Jacinto River Waste Pits Superfund Site ("SJRWP" or "Site").

The Technical Review Team has requested an extension of time to provide its comments because key Site documents and information in the possession of EPA and the U.S. Army Corps of Engineers ("USACE") have not yet been made available to us. This Corps information -- addressing problems with the temporary cap at the Site -- is critical to our ability to provide complete comments on the responsible parties' recommendations that capping be considered a potential remedy. Accordingly, the Technical Review Team has requested an extension of two weeks from the time it is provided with the key documents it has requested from the Corps to provide a complete set of comments. The Technical Review Team also understands that the U. S. Government shutdown will extend the comment period in any event, since the EPA was not available to provide other information needed for us to prepare our comments. In the interim (awaiting both the resumption of government services and the provision of the information requested and needed from the Corps to complete the comments), Harris County Pollution Control submits these initial, partial comments on behalf of The Technical Review Team as a starting point and will supplement with final comments two weeks after it receives the information from the USACE that is necessary for Harris County to provide final comments at this stage of the review.

Even while awaiting this additional information, it should be noted that The Technical Review Team's review of the site information and the responsible parties' preferred proposed remedy in the Draft FS indicates on its face that it does not comply with the requirements of Comprehensive Environmental Response, Compensation and Liability Act ("CERCLA"). For the reasons set forth in more detail in these partial initial comments, The Technical Review Team believes that the draft Feasibility Study is defective and that an additional draft Supplemental Feasibility Study or other supplemental studies and testing will need to be undertaken by the responsible parties to address the deficiencies that render the Draft FS document non-compliant under CERCLA and make the proposed remedy inappropriate for the Site.

PARTIAL INTERIM COMMENTS

The Technical Review Team's partial interim comments, to be supplemented as noted above, are presented in the following sections as: General Comments and Section Specific Comments.

General Comments:

1) As noted above, The Technical Review Team has not received the USACE Report evaluating the Time Critical Removal Action ("TCRA") and temporary, interim armored cap. This USACE document is scheduled to be provided to members of the Community Awareness Committee the week of October 14, 2013, just after these partial interim comments will be submitted to EPA on October 11, 2013. In the Draft FS the armored cap is being proposed as an essential part of the remedy being promoted by the responsible parties. It is critical that The Technical Review Team review that input in order to make meaningful comments and we have requested at least two weeks of review time for this USACE document before we can properly comment on this Draft FS. Supplemental comments will follow after that information has been made available to The Technical Review Team.

   As also noted above, The Technical Review Team is providing these comments as partial interim comments to accommodate EPA's request for comments by October 11, 2013, prior to the unanticipated event of the Federal Government shutdown. This shutdown beginning September 30, 2013, and continuing, has hampered efforts to formally document an extension, although the Government shutdown itself would render any deadlines extended by virtue of that circumstance.

2) The Technical Review Team believes that a permanent solution to significantly reduce the risk to human health and the environment is not presented and that the recommendation to leave the dioxin contamination in place does not meet the governing threshold criteria of the CERCLA. CERCLA requires and prefers remedies that permanently and significantly reduce the volume, toxicity or mobility of the hazardous substances, so that they do not migrate to cause substantial danger to present or future public health or welfare or the environment.[1] Leaving such toxic material in place in a marsh and aquatic environment is not a permanent or appropriate solution given the frequency and severity of tropical storms, floods, tidal action and hurricanes that affect the area, as well as subsidence activity. There is also an issue regarding the requirement for treatment of principal threat wastes. The Technical Review Team believes the dioxin contamination should be removed from the River ecosystem, thus eliminating the continued possibility of redistributing the

[1] See USC Title 42, Chapter 103, Section 9621, Cleanup Standards (CERCLA Section 121); USC Title 42, Chapter 103, Section 9601, Definitions (CERCLA Section 101), requiring that "remedial actions in which treatment which permanently and significantly reduces the volume, toxicity or mobility of the hazardous substances, pollutants, and contaminants is a principal element, are to be preferred over remedial actions not involving such treatment."

contamination into the Houston Ship Channel (HSC), San Jacinto River and Galveston Bay system.

3) The alternatives presented are limited and do not represent a thorough review of potential permanent and acceptable solutions.

4) In addition, The Technical Review Team does not believe that all of the Applicable or Relevant and Appropriate Requirements ("ARARs") have been established and remedial alternatives evaluated to meet them. Specifically the Texas Surface Water Quality Standards (TSWQS) including the dioxin fish tissue standard of 0.4 ng/kg TCDD Equivalents is not mentioned and the current proposed PCLs will not achieve this State standard. Therefore, the fishing advisory will never be lifted and the State Standard will not be attained. Similarly, there is no discussion of floodplain management and impact considerations of construction in the floodplain and floodwater pathways and how that would impact flood control, river pathway and water flow issues and obstructions in navigable waters, as one example. Such activities are not allowed except by permit and constructing structures that could have these impacts on a key river would be disfavored for numerous reasons. These and many other ARARS do not appear to be considered at all.

5) A Protective Concentration Limit ("PCL") based on a recreational user scenario is not acceptable. A lower PCL is required to meet the State tissue level and to support subsistence fishing which must be attained on all state water bodies.

6) Furthermore, The Technical Review Team disagrees with the assumption that fish tissue levels are decreasing in the area, as evidenced by 2012 University of Houston (UH) data. These levels have been very consistent since 1990, as evidenced by the attached data. This presents another fundamental flaw in the Feasibility Study.

   See Attachment 2 UH Sediment and Fish Data

7) It is our understanding that this Draft FS only addresses the North of I-10 Investigation Area and that a subsequent FS will address the South of I-10 Investigation Area. Therefore, the title of this Draft FS should be modified to clarify that it only applies to the North of I-10 Area.

8) Due to the many deficiencies and inconsistencies in the Draft FS, the lack of sufficient detail and the minimum number of appropriate alternatives presented, we feel this document does not meet the requirements of CERCLA.

Section Specific Comments:

1) Executive Summary

   a) The Technical Review Team believes the document is inadequate in that it does not present sufficient alternative remediation strategies which cover options or combination of options for removal and stabilization of contaminated material.

b) The Technical Review Team disagrees with the evaluations on alternatives, long term and short term environmental impacts, re-suspension of waste, impacts of sediment in the river and the general characterization of the risk as low (short term and long term).

c) The Technical Review Team disagrees with the assertion that greenhouse gases, particulate matter and ozone emissions associated with dredging alternatives would be a significant impact. The volume proposed for dredging is negligible compared to the 3 to 5 million CY of dredging occurring annually for maintenance of the HSC/Galveston Entrance.

d) The Technical Review Team disagrees with the responsible parties' recommendation that Alternative 3 is the best option for this site.

2) Section 2.2.1, Recreational and Navigational Use. It should be pointed out that there is no restriction or limitations to the general public in accessing the area within the USEPA Preliminary Site Perimeter. Any user is free to access this area as often as they like and there is no current practical way to restrict subsistence fishing. In addition, all of this area must meet all applicable state water quality standards, including the dioxin/furan/PCB TEQ value of 0.4 ng/kg fish tissue standard.

3) Section 2.4.2, Riverbed Characteristics and Sediment Transport, Page 9, the third paragraph states that "Near-bed velocities generated by episodes of propeller wash are expected to be significantly higher than those due to tidal and riverine currents"…Whereas, Section 2.2.1 states access to the TCRA Site via boat is currently constrained to the North, West, South and Southeast. This seems to be a contradiction and possibly factors affecting the modeling assumptions.

4) Section 2.5.3.1.1, Effect of Time Critical Removal Action, Sediment, Page 14, states "In addition, on-going natural recovery continues to reduce surface sediment concentrations outside of the TCRA Site, as indicated by the long-term chemical fate model simulations". As evidenced by Attachment 2, the site data does not show a decreasing trend and this statement is incorrect.

5) Section 2.5.3.1.1, page 14, states that the sediment TEQ SWAC was reduced by more than 80% by implementing the TCRA. However, concentrations measured in August 2011 as part of the TMDL project indicate that the TEQ levels at station 11193 (San Jacinto River at I-10) have not decreased (see Table 1, Attachment 2). Furthermore, TEQ sediment concentrations in the vicinity of the pits (as depicted in Figure 3-1 of the Draft FS) remain at levels comparable to those measured in the summer of 2005 as part of the TMDL study (see Table 1, Attachment 2).

6) Section 2.5.3.1.2, page 14, states in the first paragraph that 2378-TCDD and 2378-TCDF were not present in surface water over the armor cap. Because of the limitations of SPME fiber sampling, we do not believe that this statement can be supported. In addition, the SPME sample at best accounts only for the freely dissolved fraction of dioxins in water and, due to the hydrophobic nature of dioxins, a substantial part of the TEQ water column concentration will be in the suspended phase, which was not measured as part of the RI.

7) Section 2.5.5.1, Bioaccumulation, Page 17. States "bioaccumulation of PCDD/Fs cannot be understood on the basis of aggregate quantities, such as TEQ concentrations." "the majority of dioxin and furan congeners do not consistently bioaccumulate in fish or vertebrate tissue.

…As a result, systematic predictions of bioaccumulation from concentrations of dioxins and furans in abiotic media (both sediment and water) are only possible for tetrachlorinated congeners. However, even these correlations are weak, and are associated with high uncertainty."

We concur that bioaccumulation varies by congener, for reasons that are thoroughly described in the technical memo, and that bioaccumulation of the more chlorinated PCDD/Fs is limited. This has been previously reported by the UH/Parsons team in their numerous reports to the TCEQ TMDL program as well as their scientific publications (Dean et al. (2009); Dean et al. (2003); Suarez et al. (2005)). However, it is important to keep in mind that the PCDD/F risk from fish consumption is primarily due to 2378-TCDD and 2378-TCDF. While some of the larger congeners are relatively abundant by mass in fish and shellfish tissue, 2378-TCDD and 2378-TCDF are on average responsible for more than 80% of the risk-normalized concentration (expressed as TEQ) in fish and crabs, as shown in the table below. In fact, more than 80% of the TEQ in fish and 60% of the TEQ in crabs was from 2378-TCDD alone. Thus, the aggregate quantity, TEQ, primarily reflects 2378-TCDD. As the references cited in the bioaccumulation technical memorandum show, 2378-TCDD and 2378-TCDF are substantially bioaccumulated in crabs, and 2378-TCDD is bioaccumulated in catfish, in a manner and degree not unlike most other hydrophobic organic compounds. Moreover, their concentrations in fish and shellfish are roughly proportional to concentrations in sediment, implying that application of a Biota Sediment Accumulation Factor (BSAF) is appropriate to predict bioaccumulation from concentrations in sediment. This is illustrated in Figures 3 and 10 of the bioaccumulation memo, reproduced below. We do not consider these correlations to be particularly weak for a natural system, particularly after considering that fish and crabs are mobile organisms and likely to be exposed to a range of contaminant concentrations, even considering high site fidelity. Also, the variability in these BSAFs can be reduced by utilizing the typical form of the BSAF, the ratio of lipid normalized tissue concentrations to organic carbon – normalized sediment concentrations, and computing BSAFs by the method of Burkhard (2009). Moreover, we believe that the uncertainty in BSAF should not preclude its use in developing appropriate PCLs. We believe that bioaccumulation of PCDD/Fs can be understood based on TEQ due to its dominance by 2378-TCDD, though we concur that it is best to consider the bioaccumulation potential of each congener individually.

Contribution of Individual Congeners to TEQ* based on Data in the Remedial Investigation Report

Media	Fish Collection Area	2378-TCDD	12378-PeCDD	1234678-HpCDD	OCDD	2378-TCDF	12378-PECDF	23478-PeCDF	123678-HxCDF	OCDF
Sediment	1	67.3%	0.94%	1.56%	1.41%	26.9%	0.14%	1.28%	0.37%	0.07%
Sediment	2	71.7%	0.74%	0.12%	0.12%	25.7%	0.16%	1.19%	2.00%	0.01%
Sediment	3	64.1%	1.21%	5.36%	5.67%	22.4%	0.11%	0.70%	0.38%	0.13%
Crab	1	77.3%	0%	0.20%	0.03%	20.5%	0.13%	1.22%	0.65%	0%
Crab	2	67.3%	0%	0.19%	0.05%	26.9%	0.41%	4.12%	0.97%	0%
Crab	3	62.9%	0%	0.29%	0.03%	24.6%	0.96%	9.16%	2.04%	0%
Catfish	1	95.6%	2.17%	0%	0%	1.10%	0%	1.15%	0%	0%
Catfish	2	94.2%	2.56%	0%	0%	2.04%	0%	1.23%	0%	0%
Catfish	3	92.5%	4.05%	0%	0%	1.80%	0%	1.48%	0%	0%

*non-detected congeners disregarded in calculation of TEQ. TEFs were from Texas surface water quality standards 30TAC§307

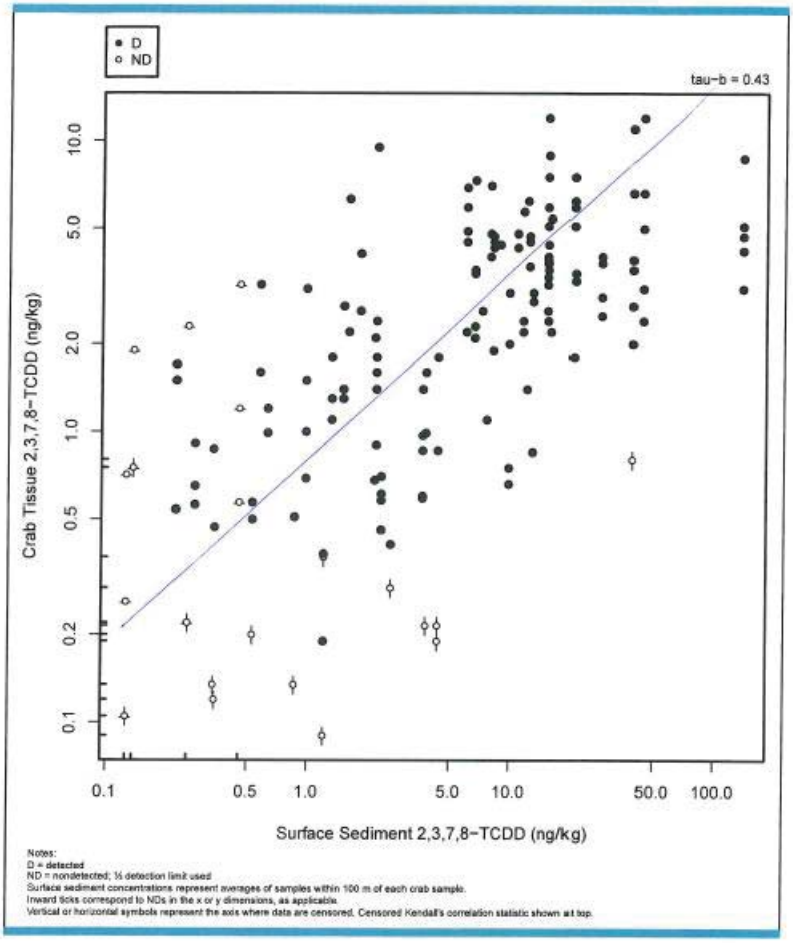

Figure 3
Relationships between Blue Crab Tissue and Surface Sediment Concentrations of 2,3,7,8−TCDD (ng/kg, ND=½DL)
Bioaccumulation Technical Memo
SJRWP Superfund/MIMC and IPC

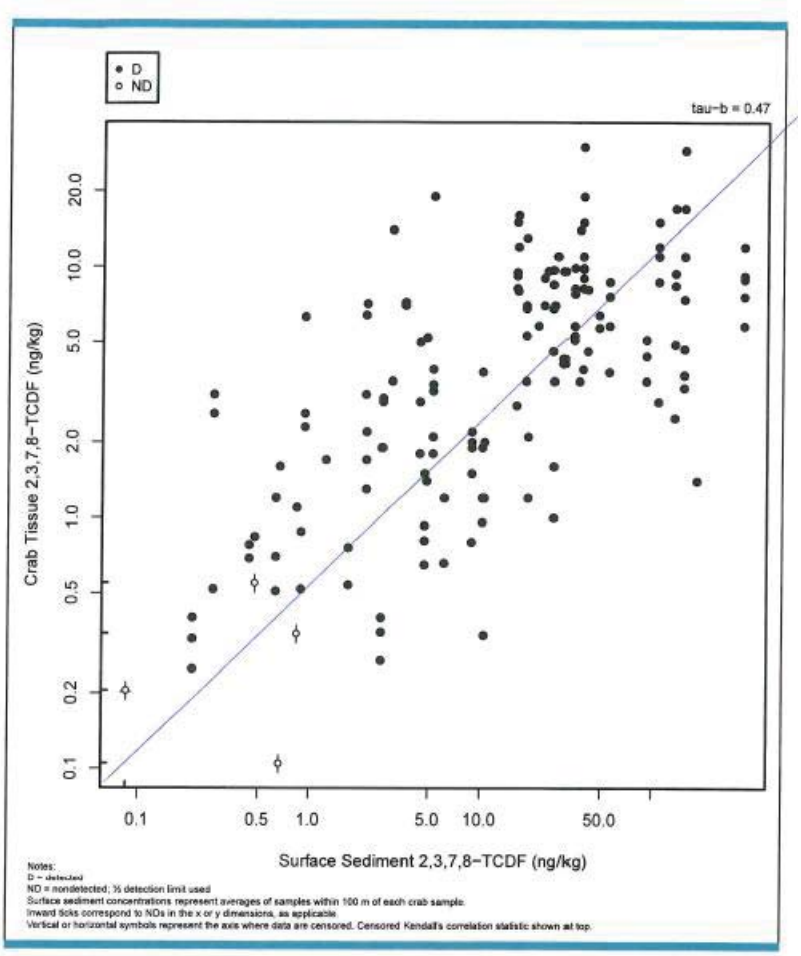

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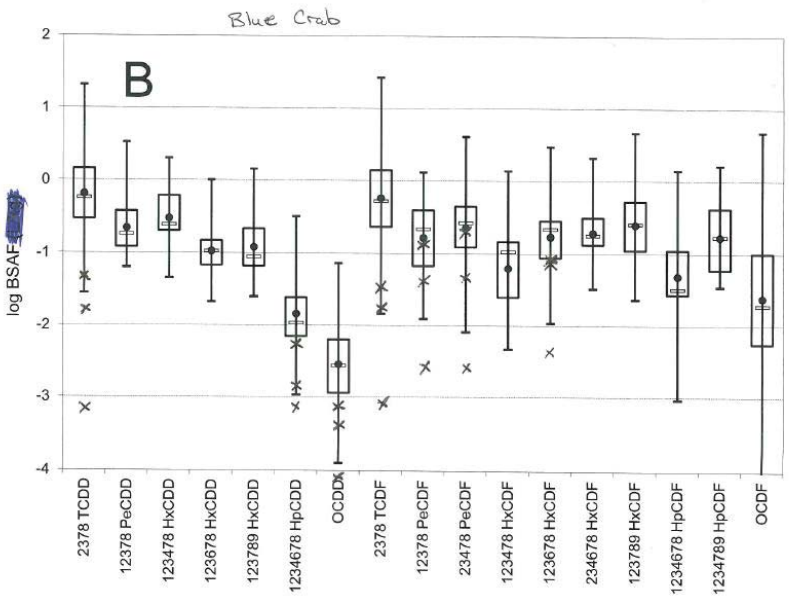
Figure 10
Relationships between Blue Crab Tissue and Surface Sediment Concentrations of 2,3,7,8−TCDF (ng/kg, ND=½DL)
Bioaccumulation Technical Memo
SJRWP Superfund/MIMC and IPC

The BSAFs reported for blue crab in the RI are anomalously low relative to those reported by the UH/Parsons team. In the figure below, the BSAFs reported for the three fish collection areas by congener are displayed with an "x" superimposed on box plots developed from data reported by UH/Parsons, which involved co-located sediment and crab samples from dozens of sampling stations throughout the Houston Ship Channel (HSC) and Galveston Bay system over several years. In many cases, the BSAFs reported are lower than any of the more than 100 values measured by UH/Parsons. This might be expected to result from a combination of high localized sediment PCDD/F concentrations in the Preliminary Site Perimeter (which constitute the denominator of the BSAF) with mobile organisms (crabs) that are exposed over their travels to less contaminated sites (and thus a lower BSAF numerator). However, the sediment PCDD/F concentrations utilized in the RI BSAF calculation are approximately equal to the average sediment concentration from the entire system reported by UH/Parsons, and the source of the low BSAF was instead found to be anomalously low levels reported in crabs from the site. The reported levels in crab are anomalously low even when compared to samples collected within the Preliminary Site Perimeter reported by UH/Parsons. We recommend that the source of this discrepancy be further investigated, as it represents one of the major PCDD/F exposure routes to humans. It may be due to differences in the size/age of the crabs collected, or judgments on what portion of the edible meat was extracted from the carapace for analysis. This discrepancy was not observed for catfish tissue.



8) Section 3.1 – Recommended Protective Concentration Levels (PCLs).

a) The 95% fish tissue TEQ concentration used in the Baseline HHRA are lower than all but one of the samples reported by UH/Parsons for fish collected within the Preliminary Site Perimeter from 2002 to 2010. Given the fact that concentrations at the site have been observed to be much higher, it seems unlikely that the numbers used in the BHHRA represent the true maximum reasonable expected concentration in the evaluation of risk from fish consumption.

b) The TEQ PCL for sediment outside the footprint of the TCRA cap was set at 220 ng/kg.

- This concentration is too high since it does not meet the maximum cancer risk level of 10^{-5} Set by TCEQ in the TSWQS and the associated fish tissue standard. The PCL was recalculated using equation 5-6 of the RI along with the common parameters and pathway specific parameters for a hypothetical subsistence fisher provided in Table H5 of the RI, and a cancer slope factor (CSF) of 10^{5} kg-day/mg. The recalculated sediment PCL is 16 ng/kg, which is lower than the proposed PCL by a factor of 14. This approach is preferable over the use of a tolerable daily intake (TDI) because USEPA uses a linear dose response model to evaluate the toxicity of 2,3,7,8-TCDD. In addition, this is the approach used to set the TSWQS (TAC §307.6). Finally, because the CSF is based on 2,3,7,8-TCDD and the other congeners present differing behaviors, the PCL should be set for 2,3,7,8-TCDD and not TEQ as a whole. To account for the carcinogen effects of the remaining congeners, the PCL for 2,3,7,8-TCDD should be a fraction of the 16 ng/kg.

- Sediment target PCL concentrations can be calculated using the tissue-based TSWQS of 0.4 ng-TEQ/kg (TAC §307.6) and average site-specific BSAFs. Sampling data collected between 2002 and 2005 as part of the TMDL Study estimated that TCDD contributes 80% of the total TEQ in tissue samples. Thus, the portion of TEQ attributable to TCDD was assumed equal to 0.32 ng/kg. Using the average BSAF of 0.34 measured in the remedial investigation, the resulting sediment target TCDD concentration would be 0.94 ng/kg.

- The cancer hazard based PCLs for TEQ in fish tissue proposed for this Superfund Site are between 1.5 and 12 ng/kg. These PCLs exceed the tissue-based TSWQS of 0.4 ng/kg, which is required to be met in all waters in Texas.

9) Section 3.3, Applicable or Relevant and Appropriate Requirements ("ARARs").

TSWQS (30 TAC §307.1-10) are one of the ARARs listed in Section 3.3. To protect human health from dioxins in fish consumption, Texas has adopted a water quality criterion of 0.4 ng/kg of 2378-TCDD TEQ in fish tissue in waters of the state. Based on the average site-specific BSAF of 0.34 measured in the remedial investigation, catfish exposed to the site sediments at 220 ng/kg TEQ (~149 ng/kg 2378-TCDD based on site area weighted concentrations) are expected to result in catfish tissue concentrations of approximately 51 ng/kg 2378-TCDD, without even considering contributions to TEQ from other congeners. This predicted concentration is more than 100 times higher than surface water quality standards which must be met. While there is uncertainty in the measured BSAFs, even the lowest measured BSAFs predict substantial exceedance of water quality standards for fish tissue. We recommend that the proposed PCLs be revised to consider this water quality standard in the ARARs. Additional ARARs must also be considered, as noted in prior sections of this document.

See Attachment 3 for TCEQ TSWQS TEQ criteria.

10) Sections 4 through 6; Section 4, Development of Remedial Alternatives; Section 5, Detailed Analysis of Remedial Alternatives and Section 6, Comparative Analysis of Remedial Alternatives

a) The only permanent solution is removal of dioxin impacted sediment and soil. As noted in more detail in prior sections of this document, this is due to the occurrence of hurricanes, tropical storms and/or flooding on the San Jacinto River which would displace the capped soil and soils outside of the capped area.

b) The alternative descriptions in Section 4 and the cost estimates in Appendix C need more details. The Draft FS document overall is very limited and abbreviated in the descriptions, analysis and alternatives presented. From the information provided, it is very difficult to properly evaluate the alternatives and potential remedies. All sections should be substantially expanded. For example, there needs to be a description of the physical properties of the soil/sediment that would be removed. More details need to be provided on the construction methods and the rationale for selection of the construction methods used. An explanation of the classification and corresponding disposal requirements for soil/sediment taken offsite for disposal needs to be provided. Backup calculations for unit costs and quantity calculations need to be provided. More explanation of the basis for evaluation of each alternative for each CERCLA criteria needs to be provided. An explanation of how the soil/sediment properties, site conditions and construction methods impact the alternative evaluation needs to be provided. The alternative evaluations in Section 5 should have sub-headings for each of the CERCLA criteria, except state and community acceptance which can only be addressed after a public comment period.

c) Of the six alternatives proposed, only two list any removal of sediment/soil as an option. Alternative 5 includes removal of 53,300 cy of sediment/soil with dioxin TEQ above 13,000 ng/kg. Alternative 6 includes removal of 208,300 (if text is correct) of sediment/soil with dioxin TEQ above 220 ng/kg. Both alternatives assume off-site disposal and costs are presented for landfill disposal and incineration. We feel there should be several alternatives which include a range of removal volumes.

d) The Draft FS should explain why costs are given for both landfill disposal and off-site incineration. Explain the conditions when incineration would be required.

e) For alternatives 1, 2 and 3, the Draft FS does not describe the potential for erosion and release due to a major storm.

f) The Draft FS does not include a section for technology screening or alternative screening. The text in Section 4 states that technology and alternative screening was done in the Remedial Alternatives Memorandum (RAM) dated Dec 2012. The Draft FS should include technology and alternative screening information to present a thorough and complete document.

g) Flooding on the San Jacinto River near the site is a serious issue. The Draft FS does not take into account that any construction in the flood way of the River must be studied for its impact on flooding and that offsets for this displacement need to be included in every alternative presented in the Draft FS that provides for any permanent structure in the flood way. This includes the issue of leaving the cap in place as it is or making any additions to its height or overall footprint.

11) Section 4.3 states that the cap in Alternative 3 would be designed to meet "No Displacement" design criteria. The "Minor Displacement" criterion was used for design of the existing TCRA cap. In addition, in Alternative 3, the slopes would be flattened from 2 horizontal to 1 vertical to 3 horizontal to 1 vertical and the armor stone would be designed for a higher factor of safety of 1.5.

12) The first sentence of Section 5.1.1 states: "The No Further Action remedial alternative would be protective of human health and the environment." The basis of this statement is the assertion that sediment with concentrations above the proposed PCL was capped during the TCRA, or is already buried by cleaner sediment. The existing cap and armor stone has been proven to be inadequate and therefore the no action alternative would not be protective of human health and the environment. In addition, the statement is not accurate and the appropriate PCL has not been determined to be protective of human health and the environment. Nor does the proposed PCL meet all appropriate ARARs (see above).

13) Section 5.1.1 states that modeling indicates that net erosion depths would be limited to less than 15 centimeters. Need to consider total erosion during severe weather events that could erode deeper and expose sediment with significantly higher concentrations.

14) Sections 5.2.1 and 5.3.1 also state that the Monitored Natural Recovery (MNR) and Capping alternatives would be protective, using the same rational as used for the NFA alternative. Again, this statement is inaccurate.

15) Section 5.4.2 states that a sheetpile does little to enhance short-term effectiveness "because of documented effectiveness issues." Although removal of the material should be accomplished, sheet pile can be designed and installed to make an effective barrier and over-come the issues listed in the

Draft FS. For example, there would not be gaps in a properly designed and installed sheet pile barrier. A sheet pile barrier could be installed outside the area of elevated contamination, which would avoid the potential for re-suspension of contaminated sediment during pile installation and removal.

16) Section 5.5.2 states the long-term effectiveness of partial dredging would be reduced by dredge residuals. As stated in other locations within these comments, we feel that better engineering controls and methods can be used to substantially reduce any long term effects from dredging. In addition, if any levels are above the appropriate PCLs, then those sediments will also be removed during the dredging process, leaving lower level residuals than the ones provide in this Draft FS document. Furthermore, if needed, residual post-dredge contamination can be eliminated by placing cover material over these areas.

17) Section 5.5.2 states that dredging may degrade the reliability of the existing containment due to scour; however, there is no explanation given. Why would this happen? With proper design, this should not be an issue.

18) Section 5.5.2 states that modeling shows long-term elevated levels in surface water and sediment concentrations due to dredging. While there may be short-term elevated levels from dredging, it would be unusual to have long-term elevated levels from dredging. The modeling assumptions should be critically reviewed and appropriate engineering controls developed. Contamination in many areas across the country is being effectively dredged and removed to substantially reduce the risk to human health and the environment.

    See Attachments 4 and 5 for other Dioxin Superfund Remedial Action efforts taking place across the country. In addition, these show PCL levels at much lower levels required to protect human health and the environment. These are much more in line with the levels we derived above.

19) Section 5.6.2 states that modeling results shows that the long-term sediment surface concentrations would be 3 times higher after dredging, compared to natural recovery. As stated above, this is an unusual prediction, especially considering that sediment and tissue levels have not changed since 1990 and may be trending upward. Thus it is unclear how this statement can be made. We recommend a critical review of the assumptions used in modeling. In addition, if dredged surfaces exceed the PCL, then they must be removed, thus decreasing the surface value predicted in modeling.

    a) The modeling results in the Draft FS are based on an assumed release of 3% of the dredged material mass. As noted in other comments, the mass of re-suspended sediment can be eliminated by rigid containment barriers around the dredge or excavation areas. Given the shallow water depths across most of the site, it is feasible to install rigid barriers in the majority of the removal area shown for Alternative 6. The only area where complete containment is not feasible is the northwest portion where the water is deeper.

    b) Footnote 4 states an assumed dissolved phase release was used in the model. Since dioxins have very low solubility, the dissolved portion would only represent a fraction of release during dredging. Since the release would largely consist of sediment-associated dioxins, likely re-deposit nearby, the actual impact to water quality will be less than predicted by the model results presented in the Draft FS.

20) In general, the Draft FS describes the potential for releases during dredging or in-situ solidification, but ignores the potential for continued release of sediment contaminants under the existing TCRA cap or the cap recommended in Alt 3.

21) The Draft FS should consider alternatives that use dredging with "on-site" containment in an upland confined disposal area which could be located in close proximity. In a similar situation in Harris County where DDT contaminated the submerged sediments of Greens Bayou, a bank-to-bank dredge was conducted to remove the source contamination and the responsible parties designed and constructed a lined upland cell to accept the material. This was a successful permanent removal of highly toxic materials from an aquatic environment into an upland disposal area where exposure pathways were permanently eliminated.

22) Given the shallow water depths, it is feasible to construct a temporary earth/rock berm around the majority of the dredge area. The berm could be placed where the existing ground surface elevation is elevation minus 1 to 2 feet (NAVD88 datum), or higher. A berm would provide complete containment of re-suspended sediment, which would eliminate impacts to water quality and sediment quality. The figures in Attachment 6 show the locations of cores with TEQ concentrations greater than 13,000 ng/kg. All four of the core locations with TEQ greater than 13,000 would be inside the potential containment berm.

    Attachment 6 shows the figure referenced.

23) The excavation could be sequenced to work from the center of the area that is above mean tide level towards the perimeter. The unexcavated area around the excavation would serve as a berm to contain re-suspended sediment. This could be done with, or without, the temporary berm described in the comment above.

24) The alternative descriptions in Section 4 need more details on items such as (a) the physical properties of the soil/sediment (especially grain size, percent solids, organic content and density), (b) the proposed construction methods and how the soil/sediment types and site conditions impact construction methods, (c) the basis for classification of excavated or dredged material for off-site disposal, (d) temporary facilities needed, (e) barge and truck haul routes, etc.

25) The cost estimates in Appendix C need to show much more detail on how the unit costs were calculated and how the quantities were calculated.

26) The quantities in Table 4-1 and the cost estimate in Appendix C do not match and need to be corrected. Specific examples are listed below:

    a) For Alternative 4, Table 4-1 lists 1,400 lf of sheet pile, but Appendix C cost table lists 800 lf.

    b) For Alternative 4, Table 4-1 lists 3,400 cy of armor rock and 6,900 cy of TCRA armor rock replacement, but Appendix C cost table lists 6,100 tons of additional armor rock, 9,000 tons of armor rock A and 5,000 tons of armor rock C/D.

c) Text in Section 4.4 says existing TCRA cap armor rock would be washed and re-used if possible. (This would also apply to Alternatives 5 and 6, but that is not stated in the text). Cost estimates in Appendix C for Alternatives, 4, 5 and 6 include cost of $682,000 for off-site disposal of TCRA riprap (i.e. armor rock). After washing, armor rock should be suitable for re-use on site.

d) Text in Section 4.5 and Table 4-1 says that Alternative 5 includes 53,300 cy of dredging. Cost estimate in Appendix C lists 7,000 cy of water-based excavation/dredging and 46,300 cy of land-based excavation, for a total of 53,300 cy of removal. Need to provide more explanation of method of construction and volumes in text and explain what removal will be done with land-based equipment and what will be done with water-based equipment.

e) Text in Section 4.6 and Table 4-1 says that Alternative 6 includes 208,000 cy of dredging. Cost estimate in Appendix C lists 208,300 cy of water-based dredging and 46,300 cy of land-based excavation. Need consistent volumes.

27) Cost estimate in Appendix C for Alternative 6 includes $10,340,000 for Mobilization/Demobilization. This is unusually high for this type of work. Please explain the components of this number.

28) Cost estimate in Appendix C shows 421,500 tons for off-site disposal in Alternative 6. If the correct removal volume is 254,600 cy (208,300 + 46,300), this is 1.65 tons per cy. For Alternative 5, the weight is 74,600 tons for 53,300 cy, or 1.4 tons per cy. The conversion from volume to disposal weight is inconsistent.

29) The cost estimate in Appendix C for Alternatives 5 and 6 only include silt curtains for containment of sediment re-suspended during dredging. No costs for sheet pile is included. Use of rigid barriers, such as sheet piles or temporary berms, would be much more effective in containing re-suspending sediment and protecting water quality and sediment quality outside the area of sediment removal.

Appendix A Comments

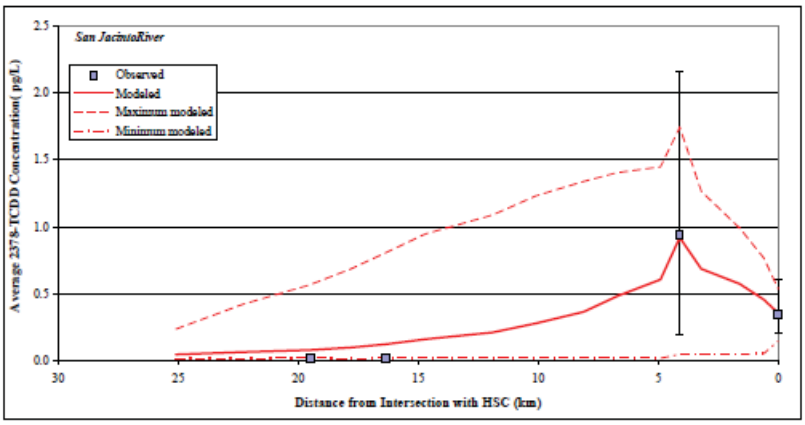
30) Section 1.1.3 of Appendix A, page 6, first paragraph indicated that "the chemical fate model predicted a decline in surface sediment concentrations within the area surrounding the USEPA's Preliminary Site Perimeter over the period from 2005- to 2010 that is within a factor of 2.5 of the decline estimated from data-based evaluations […]" Samples collected between 2002 and 2011 in the San Jacinto River for water column, fish tissue, and sediment do not support the conclusion that there have been declines of dioxin concentrations (see Figure 6, Attachment 2).

31) Section 3.2.1.1 of Appendix A, Page 19: The assumption of a dioxin/furan concentration of zero within the TCRA site footprint under future conditions seems unrealistic. It is our impression that this assumption is based on the SPME fiber sampling of pore water within and overlying the armoring substrate. We do not believe this limited type of data supports the assumption.

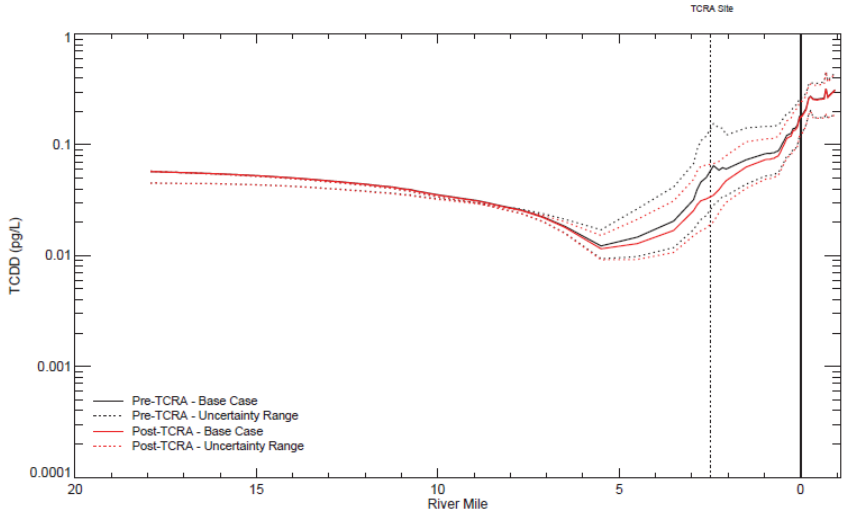
32) Section 3.2.2.1 of Appendix A, In Figure 3-14, the chemical fate and transport model for base case conditions shows water column concentrations of TCDD declining from approximately 0.06 pg/L at the upstream boundary below Lake Houston down to nearly 0.01 pg/L at river mile 5 upstream of the TCRA site, before rising to approximately 0.07 pg/L at the TCRA site, then rising further to approximately 0.2 pg/L at the lower boundary near the confluence with Buffalo Bayou. Neither these

levels nor the pattern are supported by data collected by the TCEQ TMDL effort, even considering the model uncertainty bounds. The TCEQ TMDL data, measured between 2002 and 2012 using high-volume sampling for low detection levels, showed TCDD concentrations of no more than 0.1 pg/L upstream of the TCRA site, rising sharply to approximately 1 pg/L at the I-10 bridge near the TCRA (0.23 – 2.16 pg/L, average = 1.07 pg/L, n=6), then falling to an average 0.4 pg/L at the confluence with Buffalo Bayou. For comparison purposes, the model outputs of the TMDL model (a) and Feasibility Study model (b) are reproduced below. Because model predictions do not appear to overlap with observations, even after considering model uncertainty, we are concerned that the model does not accurately simulate sources of TCDD and processes controlling TCDD concentrations. It does appear to be a reliable management tool for evaluating remedial alternatives. Additionally, because the simulated concentrations underestimate water concentrations, we believe the remediation scenarios show a much greater impact on dioxin levels in the water column than could be expected. If the initial levels are high (as supported by the sampling data), then the remediation will not affect the overall concentrations significantly.

(a) TCEQ TMDL model of TCDD in the San Jacinto River, with observed concentrations



(b) Feasibility Study Model of TCDD in the San Jacinto River



33) Section 3.2.2.2 of Appendix A, page 26, states in the first paragraph that the decline of TCDD in surface sediments within the USEPA's Preliminary Site Perimeter corresponds to a half-life of 11 years. This rate is not supported by analysis of sediment or water concentrations measured in the San Jacinto River at I-10 between 1993 and 2011. Sediment samples exhibited an increasing trend as shown in Figure 7 of Attachment 2.

Trends in biota, sediment, and water dioxin concentrations, as well as sediment cores, do not appear to exhibit any natural recovery over the past twenty years. If natural depuration processes were occurring to the extent indicated by the model-predicted dioxin half-lives, and the levels in water and adjacent sediment have not been declining, are we correct in assuming that the only way to support the observed levels and temporal and spatial trends was by substantial fluxes of dioxins from the waste pits to counteract this natural depuration? Thus, the simulated levels of natural recovery are unsupported.

34) Appendix A, Figures 3-15 to 3-18: The model predicts some very rapid natural recovery rates of TCDD concentrations in sediments and water with no further action. Please describe the key processes in the model that are primarily responsible for these reductions and present the supporting proof.

35) Section 4.2.1.2 of Appendix A, page 30, states in the last paragraph that "Potential releases of chemical mass during remediation activities were simulated in the fate model as dissolved phase flux of dioxins/furans to the water column within each remediated grid cell." Given the hydrophobic nature of dioxins, most of the release will be associated with suspended sediments, less bioavailable and more likely to re-deposit nearby.

36) Section 4.2.1.2 of Appendix A, page 32, states in the first paragraph that it was assumed in the model that releases during sediment removal for the dredging activities will occur for 13 months. This length seems long for completing dredging activities and that resulting concentrations would be this elevated with good engineering practices. Additionally, dredging will impact small areas at the time, not the entire area for the duration of the dredging activities.

37) Section 4.2.1.3 of Appendix A, Table 4-2, includes TCDD and TCDF bed concentrations for the model for dredging alternative. These concentrations are too high since dredging should be conducted along with collection of confirming sediment samples to ensure a level less or equal to the appropriate PCL. If the concentrations in the residual cover are high, dredging activities should continue until the appropriate PCL is achieved. The assumed concentrations of 198 ng/kg and 499 ng/kg for TCDD and TCDF, respectively, would result in a TEQ of 247.9 ng/kg, which is higher than even the proposed PCL of 220 ng/kg and does not include the contribution from the other congeners, therefore these assumptions are incorrect.

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Attachments:

Attachment 1 - UH Bioaccumulation Fish and Crab i1552-8618-28-11-2307

Attachment 2 - Sediment and Fish Tissue San Jac River UH

Attachment 3 - TCEQ Chapter 307 TSWQS

Attachment 4 - Dioxin Remediation Summary

Attachment 5 - Dredging Remediation at other Sites

Attachment 6- Remediation Figures

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BIOACCUMULATION OF POLYCHLORINATED DIBENZODIOXINS AND DIBENZOFURANS IN CATFISH AND CRABS ALONG AN ESTUARINE SALINITY AND CONTAMINATION GRADIENT

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Abstract—Elevated but variable levels of polychlorinated dibenzodioxins and polychlorinated dibenzofurans (PCDD/Fs) were observed in hardhead sea catfish (HH) and blue crabs (BCs), as well as in water and sediment, of the Houston Ship Channel system, Texas, USA. It is hypothesized that the variation was caused by the spatial variability of PCDD/F contamination, together with the natural mobility of organisms in satisfying prey, temperature, salinity, and reproductive requirements. Structural equation modeling was applied to explore the congener-specific relationships between PCDD/F levels in HH and BC tissues and independent predictors such as PCDD/F contamination levels, environmental factors such as salinity and temperature, temporal–spatial factors such as site depth and season, and biological factors such as length, weight, and lipid content. Contamination levels in both sediment and water were statistically significant predictors of the levels of less chlorinated congeners in both HH and BCs, with the standardized regression weight for sediment concentration roughly twice that for the water concentration. This implies that sediments are the dominant route for PCDD/F exposure and remediation efforts should focus on legacy sediment contamination. Tissue lipid content was a significant predictor of tissue concentrations in HH but only to a lesser extent in BCs, perhaps due to their low lipid content. Site depth and seasonal factors also were significant predictors of tissue concentrations. For the highly chlorinated congeners, only a small fraction of the variance in tissue concentrations was explained by the independent predictors, possibly indicating that uptake and elimination kinetics, biotransformation processes, or both may be more important factors controlling the bioaccumulation of those congeners.

Keywords—Dioxin Bioaccumulation Structural equation modeling

INTRODUCTION

Elevated levels of 2,3,7,8-substituted polychlorinated dibenzo-*p*-dioxins (PCDDs) and polychlorinated dibenzofurans (PCDFs) in hardhead sea catfish (*Ariopsis felis* Linnaeus; HH) and blue crabs (*Callinectes sapidus* Rathbun; BCs) of the Houston Ship Channel (HSC; Houston, TX, USA) system were first observed by the Texas Department of Health in 1990. Seafood consumption advisories were issued for these species at that time. Elevated PCDD/F levels have also been observed in water and sediments of the system [1]. Although the sources of contamination are believed to be primarily historical, contaminated sediments continue to serve as an internal source of PCDD/Fs to the water bodies, supplemented by other continuing sources including atmospheric deposition, runoff, and industrial and domestic wastewaters [1,2]. The levels of PCDD/Fs in fish, particularly catfish, and BCs have not been observed to decline since they were first quantified in 1990 [1]. A better understanding of the bioaccumulation behavior of PCDD/Fs in fish and crabs in the HSC may provide more accurate estimates of loading reductions necessary to achieve safe thresholds for seafood consumption.

Theory

Bioaccumulation involves the uptake of chemicals by aquatic organisms from their environment via multimedia exposures. It can include direct uptake from the aqueous dissolved phase, via respiratory exchange or dermal transfer, and dietary exposure with gastrointestinal uptake. In the equilibrium partitioning (EqP) model [3], the bioaccumulation of PCDD/Fs and other nonpolar hydrophobic organic compounds by aquatic organisms is commonly considered to be linearly related to the lipid content of the tissue (which indicates the sorptive capacity of the tissue), the fugacity of the contaminant in the system in which the organism is exposed, and the hydrophobicity of the contaminant (usually indicated by an octanol–water partition coefficient). The fugacity, or partial pressure, of the contaminant is the concentration in an environmental medium divided by the fugacity capacity of that medium [4]. At thermodynamic equilibrium, the fugacities in various phases are equal. The soot or organic carbon content is commonly considered to control the fugacity capacity of sediments [5,6], while lipid content is considered to control the fugacity capacity of most tissues [7]. In water, suspended solids and dissolved and colloidal organic carbon content may increase the fugacity capacity [8]. Given efficient dietary uptake and minimal biotransformation, biomagnification of contaminants in the tissues of organisms can occur when tissue fugacities exceed those in the surrounding environment (water and sediments).

The bioaccumulation factor (BAF) has been defined by the U.S. Environmental Protection Agency (U.S. EPA) as the ratio (in liters per kilogram of tissue) of the concentration of a chemical in the tissue of an aquatic organism to its concentration in water in situations where both the organism and its food are exposed and the ratio does not change substantially over time [9]. Recognizing the importance of

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tissue lipid content on the fugacity capacity of tissue, and that of suspended solids and dissolved and colloidal organic content on the apparent fugacity capacity of water, the U.S. EPA also defined a baseline BAF as a BAF that is based on the concentration of chemical freely dissolved in water and the concentration of the chemical in the lipid fraction of tissue. The BAF is an equilibrium concept and accounts for uptake and elimination from all sources and processes, including uptake via the diet and across the gill surface. Similarly, a biota–sediment accumulation factor (BSAF) has been defined as the ratio (in kilograms of sediment organic carbon per kilogram of lipid) of the lipid-normalized concentration of a chemical in tissue of an aquatic organism to its organic carbon-normalized concentration in surface sediment in situations where the ratio does not change substantially over time, both the organism and its food are exposed, and the surface sediment is representative of average surface sediment in the vicinity of the organism.

Although the EqP model is useful in predicting the potential bioaccumulation of contaminants, many studies [10–17] have shown that it sometimes fails to accurately predict observed BAFs and BSAFs. Of particular concern with PCDD/Fs, large and extremely hydrophobic compounds may not achieve the levels of bioaccumulation predicted by the EqP model. Various explanations have been offered for these observations. Chemical fugacities in sediments may not be in equilibrium with those in the overlying water column, resulting in variable bioaccumulation depending on the major route of exposure of an organism (sediment versus water) and that of its prey [10]. In addition, the EqP model does not account for variations in the composition of tissue lipids [18] and sediment organic matter [11,19] that affect bioavailability or fugacity capacity of these phases. The permeation of large molecules through cell membranes may be substantially hindered due to steric factors [11–13,20], thus limiting their bioaccumulation. Low dietary uptake efficiencies [14,15] and rapid elimination via feces [15,21] and biotransformation [10,15,16] may also limit the bioaccumulation for these compounds. Finally, the EqP model does not explicitly account for changes in an organisms' diet [11], reproductive status, nutritional status, growth [21,22], or mobility [17], to the extent that they occur at a rate faster than the compounds are taken up or eliminated from tissue.

The relative impact of water and sediments in determining bioaccumulation is of major interest to evaluating the effectiveness of various contamination remediation strategies. If the majority of contaminant bioaccumulation occurs via a sediment route, the remediation of legacy sediment contamination may be necessary. On the other hand, if contaminant bioaccumulation occurs via a waterborne route, it may be more effective to achieve further reductions of ongoing discharges and deposition of PCDD/Fs to water.

Study area

The HSC is a dredged channel 13.7 m deep and 162 m wide extending approximately 86 km from the Gulf of Mexico at Galveston to near downtown Houston. The lower 46 km of the HSC extend unconfined from the Gulf of Mexico through Galveston Bay, a large (1,317 km^2), shallow (2.1 m average depth) embayment. The middle 15 km of the HSC from Morgan's Point up to the confluence with the San Jacinto River are partially confined, but numerous small, shallow embayments abut and connect to the HSC. Upstream of the confluence with the San Jacinto River, the HSC runs 25 km westward along Buffalo Bayou in a confined channel with several tributary bayous.

The HSC–Galveston Bay system is tidally influenced, and freshwater inflow exerts a strong influence on salinity levels. In most parts of Galveston Bay, salinities average 15‰, indicating approximately equal contributions of freshwater and saltwater. The salinities decline with distance upstream, and average salinities are approximately 6‰ in the upper reaches of the HSC. In tidal tributaries to the upper reach of the HSC, salinities are often less than 1‰. Freshets occur throughout the year, associated with major rainfall events, but inflow is typically highest in April and May and lowest from July through October. A moderate vertical salinity gradient typically occurs in the deep channels, with denser saltwater inflows along the bottom and freshwater inflows on top. However, vertical mixing tends to be strong in the system and the shallow bays are seldom stratified.

Contamination due to PCDD/Fs is not uniform throughout the HSC system. Two areas in the upper reaches of the HSC system are particularly contaminated with PCDD/Fs [1,2]. An industrial waste pit was operated in the 1960s and 1970s along the banks of the San Jacinto River near Interstate Highway 10. With land subsidence of several feet in recent decades, the waste pit was submerged in the San Jacinto River, likely causing substantial PCDD/F contamination throughout the HSC system. The level of 2,3,7,8-tetrachlorodibenzo-*p*-dioxin (TCDD) exceeded 20,000 ng/kg dry weight in one sediment sample from this site. A more diffuse area of elevated PCDD/F levels in sediment occurs in the Buffalo Bayou portion of the HSC upstream of the confluence with the San Jacinto River, with TCDD levels as high as 650 ng/kg in sediments. Levels of PCDD/Fs tend to decline with distance upstream and downstream from these two most contaminated areas, and PCDD/F levels in the water and sediment of upper Galveston Bay are much lower than in the more contaminated areas, with TCDD levels seldom exceeding 1 ng/kg in sediment. Concentrations of PCDD/Fs in water exhibit less spatial variation than those in sediment. Median levels of TCDD in water were 1.1 pg/L near the most contaminated site in the San Jacinto River at Interstate Highway 10, 0.23 pg/L in the more contaminated areas of the HSC upstream of the San Jacinto River, and 0.05 pg/L in upper Galveston Bay.

Both BCs and HH live and feed primarily along the sediment surface and are opportunistic omnivores and scavengers that occupy a similar midtrophic level niche. The diet of HH in the HSC system is dominated by shrimp, crabs, stomatopods, organic detritus, and small fish [23]. The diet of BCs includes mollusks, shrimp, crabs, small fish, plants, and organic detritus [24].

Both BCs and HH are sensitive to the temperature and salinity variations in a subtropical estuary. During winter months, when average water temperatures fall below 15°C, HH are rare in the HSC system and are believed to migrate into the deeper offshore waters of the Gulf of Mexico [25]. Large volumes of freshwater inflow may also cause HH to migrate periodically from the upper and middle reaches of the HSC to the lower reaches of Galveston Bay and the Gulf of Mexico. McElyea [26] reported a strong positive correlation between HH abundance and salinity in the upper HSC.

Adult male BCs tend to prefer the low-salinity waters of the upper estuary and are the dominant sex in most of the HSC system, while females prefer salinities above 20‰ and migrate to the Gulf of Mexico to spawn [24]. The abundance of BC in

the upper HSC was observed to be positively correlated with temperature [26], and crabs may migrate to the deeper waters of the Gulf of Mexico or burrow into mud and enter a state of torpor during the winter [27].

The spatial variability of PCDD/F contamination in the HSC system, together with the mobility of HH and BCs (due to food availability, life cycles, and their environmental preferences for temperature and salinity conditions), results in spatially and temporally variable exposures to PCDD/Fs. For risk assessment purposes, the seasonal and spatial variation in bioaccumulation was of particular interest. Temporally and spatially uniform tissue fugacities (lipid-normalized concentrations) of PCDD/Fs would imply that the processes of biouptake and elimination were slow relative to the variations in PCDD/F exposures. On the other hand, relatively constant BAFs and BSAFs would indicate that these species achieved rapid equilibrium with the exposure conditions at the site and time they were sampled.

MATERIALS AND METHODS

At each site, approximately 700 L of water were pumped at a rate of 1.6 L/min through an Infiltrex 300 high-volume water sampling system (Axys Technologies). Water was first passed through a wound glass fiber filter cartridge (10 cm long × 6.4 cm diameter) with a 1-μm effective pore size in order to trap particle-associated PCDD/Fs. The filtrate was then passed through a stainless steel column packed with approximately 250 g of Amberlite® XAD-2 hydrophobic cross-linked polystyrene resin (Rohm and Haas) to trap dissolved PCDD/Fs. Experiments with two XAD-2 resin columns in series showed that they trapped dissolved PCDD/F efficiently, with little or no breakthrough to the second column. The PCDD/Fs associated with colloids such as humic substances were considered to pass through the XAD-2 columns at the neutral–high ambient pH of the HSC. Other investigators using similar hydrophobic resin columns observed that more than 90% of the dissolved and colloidal organic carbon passed through the columns [12,28]. However, the size of the colloidal pool of PCDD/Fs was not measured, nor was its passage through the XAD-2 cartridge verified. Simultaneously with PCDD/F sampling, grab samples were collected for measurement of total suspended solids and total and dissolved organic carbon. Temperature, salinity, specific conductance, pH, and dissolved oxygen were measured with a YSI 600XLM sonde.

Surface (0–5 cm) sediment samples were collected with a stainless steel Ponar dredge. At each site, a minimum of three grab samples were deposited in a stainless steel bowl and mixed thoroughly with a stainless steel spoon. Composite subsamples were then deposited into a labeled, precleaned amber glass jar with a Teflon®-lined lid and stored at less than 4°C until analysis.

Biota samples

We collected HH and BCs from 45 sites throughout the HSC system during the spring, summer, and fall seasons from 2002 to 2004. Site locations are shown in Suarez et al. [2]. A total of 108 paired HH, sediment, and water samples and 155 paired BC, sediment, and water samples were collected from the 45 sites.

Hardhead catfish were collected using gill nets, fish traps, or hook and line. All specimens were adults exceeding 28 cm in length. Blue crabs were collected using baited crab traps, and with few exceptions, all specimens exceeded the legal minimum carapace width of 12.7 cm. Specimens were weighed and measured, and then HH were filleted to extract muscle portions, and edible meat portions of BC were extracted. The selected tissues from each specimen were then composited and homogenized with two to four other specimens of the same species collected from the same site on the same date. These were stored frozen until analysis.

An effort was made to collect the BC, HH, sediment, and water samples from a given site on the same day. However, this proved difficult in practice and the samples from various media for a given station were collected as much as two weeks apart.

Chemical analyses

The levels of the 17 2,3,7,8-substituted tetra- through octachlorinated PCDDs and PCDFs in water, sediment, and tissue samples were quantified by high-resolution gas chromatography or high-resolution mass spectrometry using U.S. EPA method 1613 revision B (www.epa.gov/waterscience/methods/method/dioxins/1613.pdf) at a U.S. EPA–certified commercial laboratory. Tissue lipid content was determined gravimetrically by U.S. EPA method 1613B. Sediment organic carbon content was determined in a carbon, hydrogen, and nitrogen elemental analyzer following acidification for removal of inorganic carbon. Further details on analytical methods and quality control are provided in Suarez et al. [1,2].

Statistical analyses

Bioaccumulation factors and BSAFs were calculated for HH and BCs for each of the 17 congeners quantified for paired samples where PCDD/F concentrations were quantifiable in both the tissue and the sediment (for BSAFs) or in the water-dissolved phase (for BAFs). Both BAFs and BSAFs were calculated using lipid-normalized tissue concentrations.

Structural equation modeling (SEM), a multivariate statistical technique similar to multiple regression that describes a network of complex linear relationships among variables [29], was applied to ascertain the factors influencing bioaccumulation. Several potential influential factors related to PCDD/F concentrations in tissue (on a wet weight basis) were considered in exploratory SEM: PCDD/F concentrations in sediment and water (total, dissolved, and suspended), characteristics of the organisms (length, weight, length to weight ratio, and lipid content), water characteristics (temperature, salinity, pH, dissolved organic carbon, and suspended solids concentration), sediment organic carbon content, spatial variables (site depth and distance from various points), and temporal variables (year, season, month, Julian day number [1–365], and air temperature). The sampling site depth primarily distinguishes bay sites from the much deeper channel sites. Factor analysis was used to extract from the spatial variables two major factors, one indicating the distance along the channel from downtown Houston toward the Gulf of Mexico and a second indicating the distance along the San Jacinto River channel. However, it was noted that the spatial factors strongly covaried with contaminant concentrations; thus, they were not used in further analyses. The air temperature used was the average air temperature in Houston from 1970 to 2000 for each Julian day number, which peaks in the summer and then declines, whereas the Julian day number increases throughout the year.

As preliminary results indicated that models attempting to apply to all congeners and both HH and BCs neither fit well nor explained much of the observed variation, separate SEMs were developed for each species, and for each congener with more

Table 1. Summary of measured 2,3,7,8-substituted polychlorinated dibenzodioxins and polychlorinated dibenzofurans congener concentrations in various media[ab]

	Blue crab muscle, pg/g (n = 155)			Hardhead catfish fillets, pg/g (n = 108)			Dissolved concentration, pg/L (n = 148)			Sediment concentration, pg/g (n = 174)		
Congener	Min.	Median	Max.	Min.	Median	Max.	Min.	Median	Max.	Min.	Median	Max.
2378-TCDD	<0.18	2.2	12	<0.36	5.15	26	<0.003	0.038	0.441	<0.23	6.45	650
12378-PeCDD	<0.10	<0.29	1.5	<0.10	0.36	4.5	<0.003	<0.007	0.028	<0.33	<0.85	13
123478-HxCDD	<0.09	<0.21	1.4	<0.10	<0.24	6.8	<0.003	0.009	0.035	<0.12	1.85	12
123678-HxCDD	<0.11	0.27	3.1	<0.11	0.64	7.6	<0.004	0.014	0.199	<0.29	3.95	71
123789-HxCDD	<0.10	<0.23	1.7	<0.11	0.29	7.5	<0.004	0.018	0.082	<0.48	3.60	24
1234678-HpCDD	<0.23	0.74	4.2	<0.41	1.15	10	0.030	0.416	4.27	1.90	120	2,100
12346789-OCDD	0.35	3.4	62	0.59	2.8	20	0.227	8.27	80.7	39	3,100	41,000
2378-TCDF	<0.21	3.8	30	<0.12	0.44	4.6	0.009	0.131	1.22	<0.16	18.5	1,600
12378-PeCDF	<0.10	<0.28	1.7	<0.07	<0.24	5.0	<0.003	0.010	0.199	<0.2	1.05	170
23478-PeCDF	<0.09	0.35	1.7	<0.12	0.54	4.4	<0.004	0.012	0.118	<0.23	1.80	180
123478-HxCDF	<0.09	<0.23	2.0	<0.07	<0.19	6.5	<0.002	0.012	0.242	<0.17	2.10	370
123678-HxCDF	<0.08	<0.20	1.6	<0.07	<0.22	7.8	<0.002	<0.009	0.257	<0.23	1.40	110
234678-HxCDF	<0.07	<0.21	1.6	<0.03	<0.21	7.5	<0.003	0.007	0.114	<0.19	1.30	51
123789-HxCDF	<0.07	<0.21	1.9	<0.03	<0.26	6.4	<0.001	<0.005	0.048	<0.20	0.67	88
1234678-HpCDF	<0.12	<0.39	14	<0.05	<0.36	9.0	<0.003	<0.054	2.21	<0.19	16.0	1,500
1234789-HpCDF	<0.10	<0.27	1.5	<0.04	<0.29	10	<0.002	<0.009	0.138	<0.25	1.70	160
12346789-OCDF	<0.21	1.0	410	<0.26	0.82	72	<0.018	0.185	38.5	<2.3	110	42,000
Tissue lipid content (%)	0.1	0.8	1.6	0.2	1.8	4.0						
Sediment organic carbon (%)										0.1	1.3	5.4

[a] n = number of samples analyzed. Each sample was composed of three to five individuals.
[b] Max. = maximum; Min. = minimum; TCDD = tetrachlorodibenzo-*p*-dioxin; PeCDD = pentachlorodibenzo-*p*-dioxin; HxCDD = hexachlorodibenzo-*p*-dioxin; HpCDD = heptachlorodibenzo-*p*-dioxin; OCDD = octachlorodibenzo-*p*-dioxin; TCDF = tetrachlorodibenzofuran; PeCDF = pentachlorodibenzofuran; HxCDF = hexachlorodibenzofuran; HpCDF = heptachlorodibenzofuran; OCDF = octachlorodibenzofuran.

than 40 measured values above the analytical detection limit in each of the tissue, sediment, and dissolved phases: TCDD, 1,2,3,6,7,8-hexachlorodibenzo-*p*-dioxin, 1,2,3,4,6,7,8-heptachlorodibenzo-*p*-dioxin, octachlorodibenzo-*p*-dioxin (OCDD), 2,3,7,8-tetrachlorodibenzofuran (TCDF), 2,3,4,7,8,-pentachlorodibenzofuran, and octachlorodibenzofuran (OCDF).

Structural equation modeling with maximum likelihood estimation was performed using AMOS 6.0 software (SPSS). The relative quality of model fit was judged by the chi-square statistic relative to the degrees of freedom, the squared multiple correlation between the dependent variable and the independent predictors, the root-mean square error of approximation, and the Akaike Information Criteria [30]. Except as otherwise noted, explanatory variables were retained in the model only if their regression weight was significantly different from zero with 95% confidence. Similarly, covariance among explanatory variables was generally retained in a model only if it was statistically significant ($\alpha < 0.05$). Structural equation models were rejected if they could be statistically rejected at $\alpha < 0.05$ based on the chi-square statistic and degrees of freedom. Other statistical analyses were performed using SPLUS software (Insightful).

RESULTS AND DISCUSSION

Concentrations of the 2,3,7,8-substituted PCDD/Fs in HH fillets ranged from less than 0.03 to 72 ng/kg and from less than 0.07 to 410 ng/kg in BC tissue (Table 1). Levels of the tetra-chlorinated congeners TCDD and TCDF were typically among the highest of the PCDD/F congeners in tissues. However, tissue concentrations of OCDD and OCDF often exceeded the levels of TCDD and TCDF. The median lipid content of BC and HH tissues was 0.8 and 1.4%, respectively.

Levels of TCDD and TCDF in HH and BC tissue appeared to be related to concentrations in sediment organic carbon and water sampled from the same site, implying that the tissues were at least partially in equilibrium with the levels in sediment and water. However, concentrations of the more chlorinated PCDD/F congeners in tissue were only weakly related to levels in sediment and water, if at all.

Tissue concentrations were significantly related to lipid levels in most cases, but the relationship was usually weaker than expected from thermodynamics-based EqP theory. This was particularly true for the more chlorinated congeners and for BC. The routine practice of lipid normalization for calculating bioaccumulation has been found by others studying animals with low lipid content to be inappropriate [31]. Stowe et al. [32] observed that lipids were only a modest predictor of polychlorinated biphenyl concentrations in Lake Michigan salmonids at the individual organism level, and Bonn [33] observed that lipid and sediment organic carbon normalizations did not reduce variance in PCDD/F fish tissue–sediment relationships.

Median lipid-normalized baseline log BAFs ranged from 4.41 to 6.68 L/kg in HH and from 4.91 to 7.03 L/kg in BCs (Fig. 1). Median log BSAFs ranged from −3.19 to −0.41 in HH and from −2.57 to −0.24 in BCs (Fig. 2). With the exception of TCDF and possibly 1,2,3,7,8,9-hexachlorodibenzofuran, the magnitude and congener patterns of bioaccumulation in BCs were similar to those for HH, likely an indication of the importance of chemical properties in controlling bioaccumulation. However, bioaccumulation of TCDF was substantially lower in HH than in BCs, and this pattern was even more accentuated with lipid normalization. A substantially reduced bioaccumulation of TCDF, relative to that of TCDD and other PCDF congeners, was also noted by Sijm et al. [34] in goldfish. They calculated a half-life for TCDF of 3.1 d in control fish but more than 7 d in fish exposed to an inhibitor of PCDD/F biotransformation, implying that biotransformation of TCDF is responsible for the reduced bioaccumulation. Loonen et al. [35] also noted rapid elimination of TCDF from guppies, with a half-life of 2.4 d compared

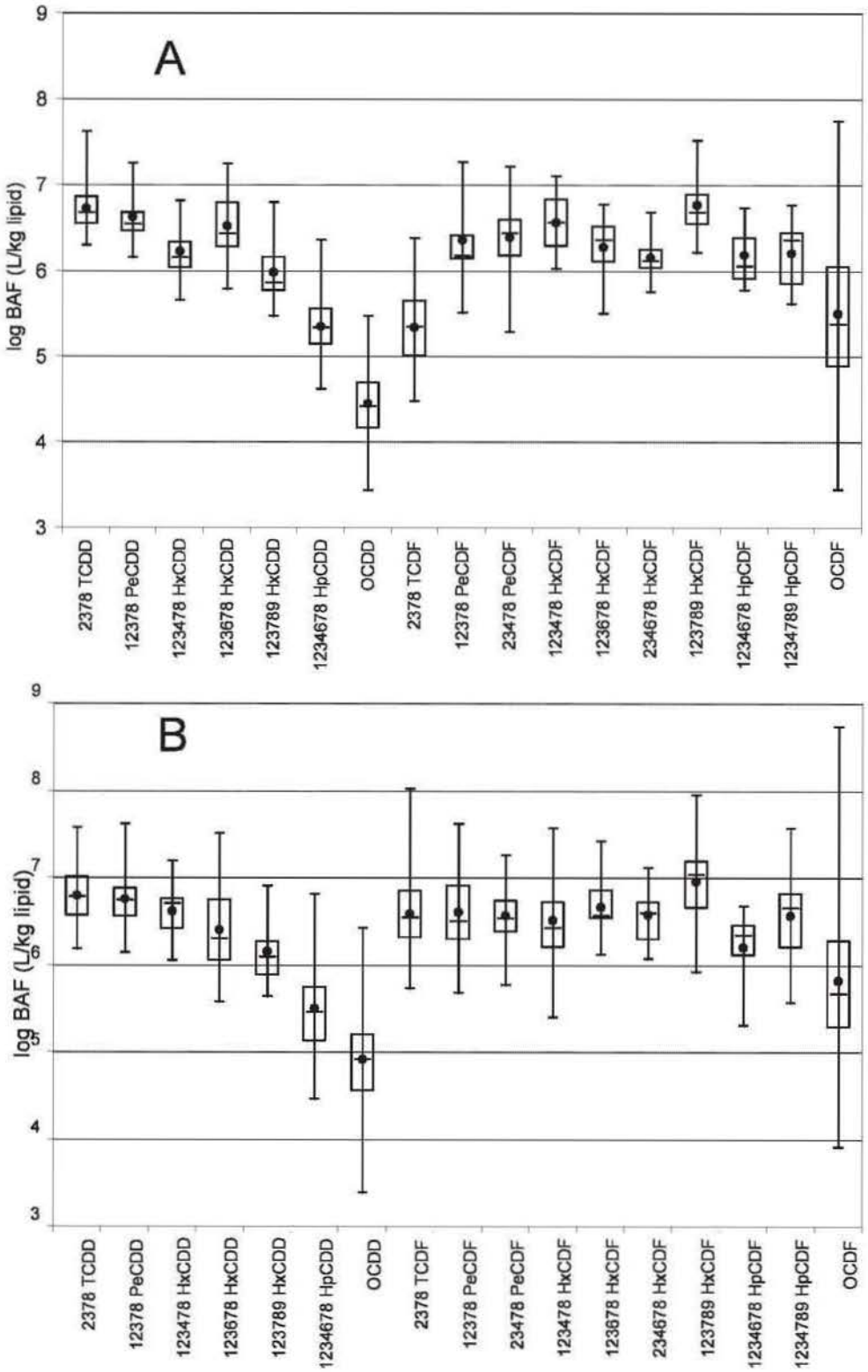

Fig. 1. Bioaccumulation factors (BAFs) of polychlorinated dibenzo-*p*-dioxin and dibenzofuran congeners in hardhead catfish (**A**) and blue crab (**B**). The first and third quartiles are represented by the vertical extent of each box, the mean by a black dot, the median by a horizontal line inside each box, and the minimum and maximum by the extent of the vertical lines extending above and below each box. Congener names are abbreviated for tetrachlorodibenzo-*p*-dioxin (TCDD), pentachlorodibenzo-*p*-dioxin (PeCDD), hexachlorodibenzo-*p*-dioxin (HxCDD), heptachlorodibenzo-*p*-dioxin (HpCDD), octachlorodibenzo-*p*-dioxin (OCDD), tetrachlorodibenzofuran (TCDF), pentachlorodibenzofuran (PeCDF), hexachlorodibenzofuran (HxCDF), heptachlorodibenzofuran (HpCDF), and octachlorodibenzofuran (OCDF).

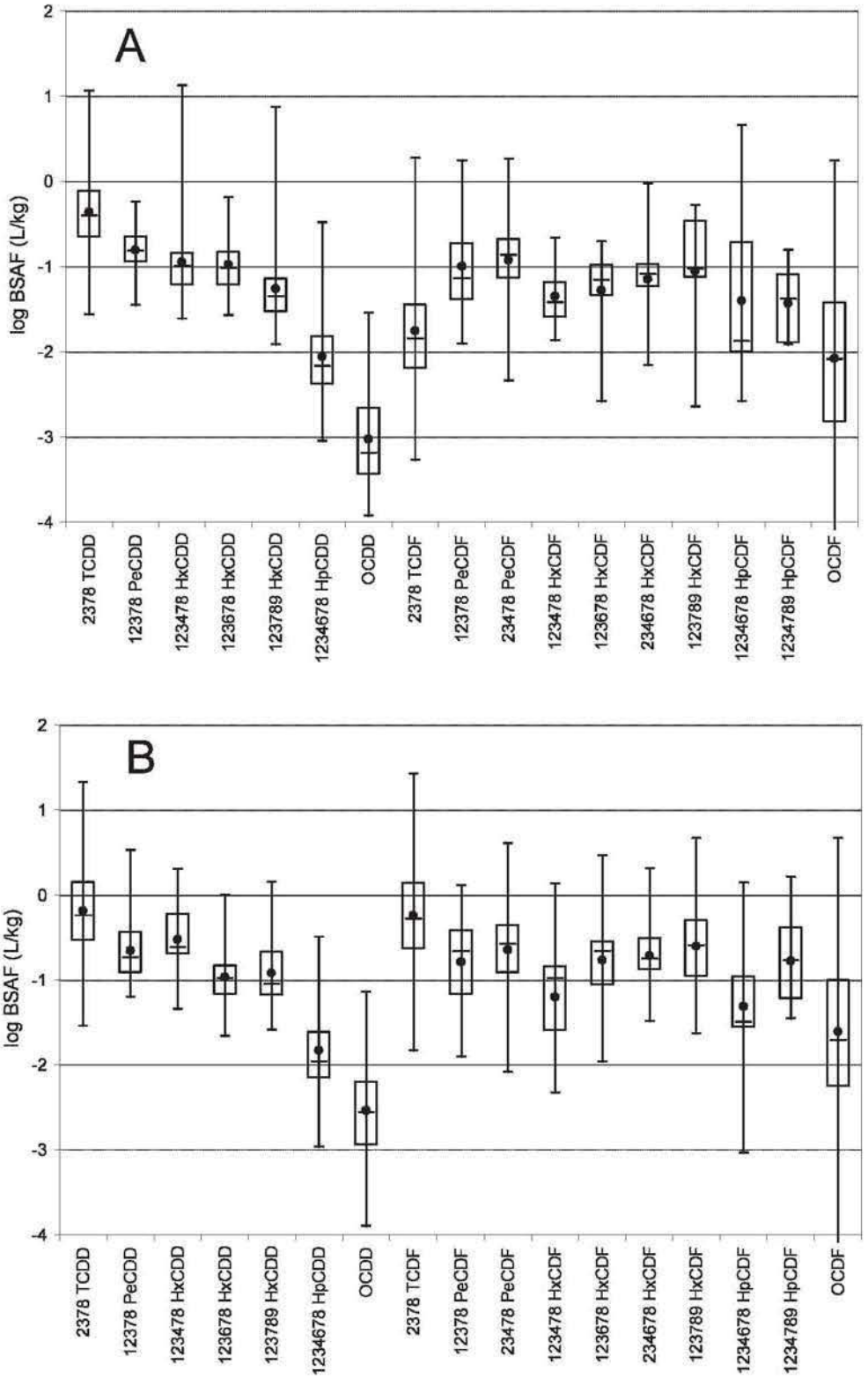

Fig. 2. Biota–sediment accumulation factors (BSAFs) of polychlorinated dibenzo-*p*-dioxin and dibenzofuran congeners in hardhead catfish (**A**) and blue crab (**B**). Congener names are abbreviated for tetrachlorodibenzo-*p*-dioxin (TCDD), pentachlorodibenzo-*p*-dioxin (PeCDD), hexachlorodibenzo-*p*-dioxin (HxCDD), heptachlorodibenzo-*p*-dioxin (HpCDD), octachlorodibenzo-*p*-dioxin (OCDD), tetrachlorodibenzofuran (TCDF), pentachlorodibenzofuran (PeCDF), hexachlorodibenzofuran (HxCDF), heptachlorodibenzofuran (HpCDF), and octachlorodibenzofuran (OCDF).

to 14 d for TCDD. Bignert et al. [36] noted large spatial differences in the bioaccumulation of TCDF, relative to other congeners, by herring in Bothnian Bay.

For the PCDD congeners, a systematic decline in BAF and BSAF with increasing degree of chlorination, molecular size, and octanol–water partition coefficient (Fig. 3A) was noted, as has been reported by previous investigators [17,37]. This pattern is consistent with the hypothesis that permeation of cell membranes is sterically limited for larger PCDDs [11–13,20]. Low dietary uptake efficiency [14–15,38] may also limit

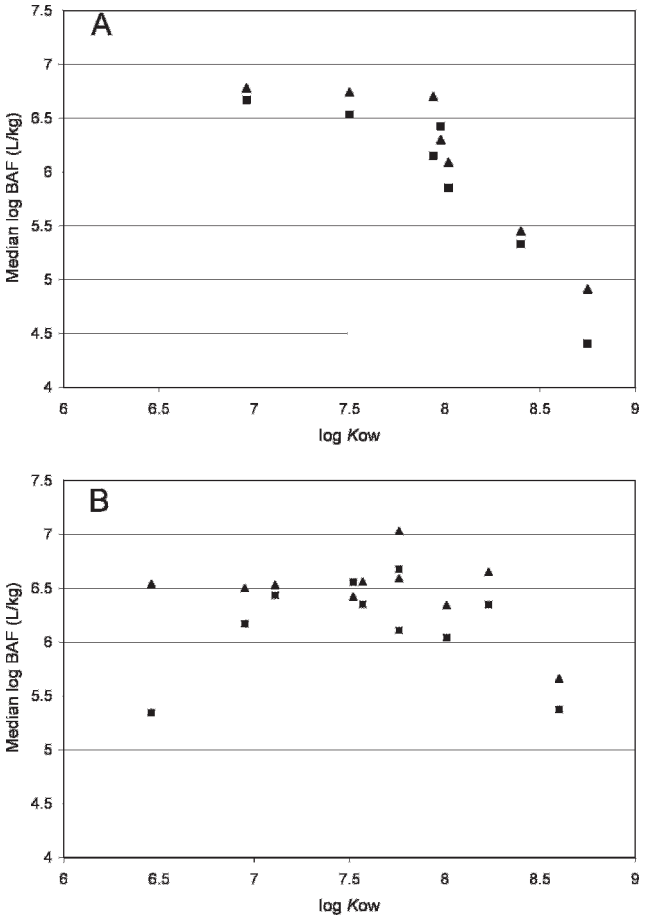

Fig. 3. Relationships between bioaccumulation factors (BAFs) of polychlorinated dibenzo-*p*-dioxins (**A**) and polychlorinated dibenzofurans (**B**) and their octanol–water partition coefficients (K_{OW}) in hardhead catfish (■) and blue crabs (▲). Values of K_{OW} are from Govers and Krop [40].

uptake of these high molecular weight congeners. Finally, given that the more chlorinated congeners also tend to be less water soluble and more prone to being strongly sorbed to sediments, alternative hypotheses involving reduced bioavailability [10] may also explain the observations.

The pattern of declining bioaccumulation with degree of chlorination was not evident to the same extent for PCDF congeners (Fig. 3B). In fact, the average BAFs and BSAFs for TCDF in HH were among the lowest of any PCDD/F congener. The absence of an observed reduction in bioaccumulation with increasing molecular size for the PCDF congeners (except for OCDF), and the apparent reduction in bioaccumulation for TCDF in HH relative to BCs, appears more consistent with a hypothesis that metabolism limits bioaccumulation of PCDFs. Burkhard et al. [10] have shown that metabolism and reduced assimilation efficiencies of PCDD/Fs reduce their BSAFs in lake trout by up to four orders of magnitude below those of relatively unmetabolizable polychlorinated biphenyls of comparable hydrophobicity. However, it should be noted that some other studies [17,37] have observed a systematic reduction in bioaccumulation with molecular size for the PCDFs congeners.

At less contaminated sites, observed BAFs and BSAFs were typically higher than those from sites where PCDD/F concentrations were higher (as illustrated in Fig. 4 for TCDD). This has been observed elsewhere [39] and may be explained as

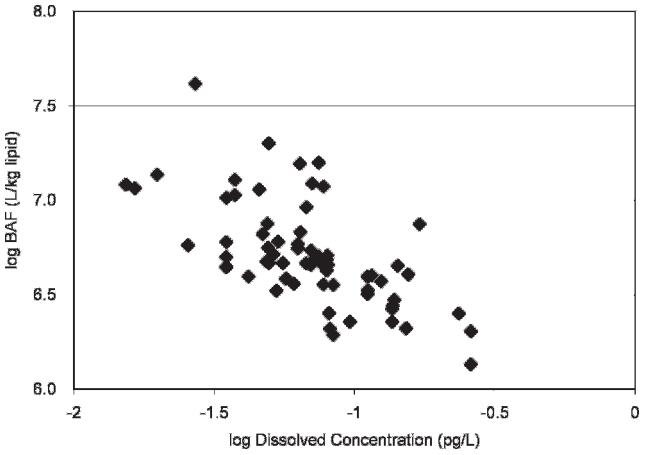

Fig. 4. Relationship between bioaccumulation factors (BAFs) in hardhead catfish and dissolved concentrations for 2,3,7,8-tetrachlorodibenzo-*p*-dioxin.

follows: HH, BCs, and some of their prey are mobile organisms, and water concentrations are dynamic, so they are exposed to PCDD/F levels from more and less contaminated sites that do not represent only the site and time where they are collected. Thus, it is important to evaluate the risks of contaminant bioaccumulation in light of the temporal and spatial variability of exposure, as well as the mobility and life history of the species.

Structural equation modeling

Hardhead sea catfish. Figure 5A shows a rather complex network of factors affecting the levels of TCDD in HH tissue. This SEM explained 62% of the variance in measured concentrations, with the balance attributed to other factors not in the model (including measurement error). The tissue concentration showed a strong positive association with lipid content, with a standardized regression coefficient of 0.47. A strong association was also seen between tissue and sediment TCDD concentrations (standardized regression coefficient = 0.35). Sediment concentrations exerted more than twice as much influence on tissue concentrations as did dissolved concentrations (standardized regression coefficient = 0.15). As expected, strong covariation (0.63) occurred between sediment and dissolved concentrations. Other statistically significant factors related to tissue levels were the site depth and the Julian day number of the year. The relationship with depth primarily reflected that TCDD tissue levels of HH collected in the deep channels tended to be higher than those collected in the bays, even after accounting for the covariation between dissolved concentrations and depth (no significant independent covariation occurred between depth and sediment concentration). The covariance between dissolved TCDD concentrations and site depth likely reflected that many of the shallower Galveston Bay sites were less contaminated than those in the more confined HSC upstream. A weak but statistically significant relationship between TCDD concentrations in tissue and Julian day number was observed, which implied that tissue TCDD levels declined as the year progressed. Given that HH are known to migrate from the HSC system to presumably less contaminated waters over the winter, this result is counterintuitive. The possibility that this observation could be explained by autumn recruitment of less-contaminated juveniles into the size ranges collected was considered. However, fish length and

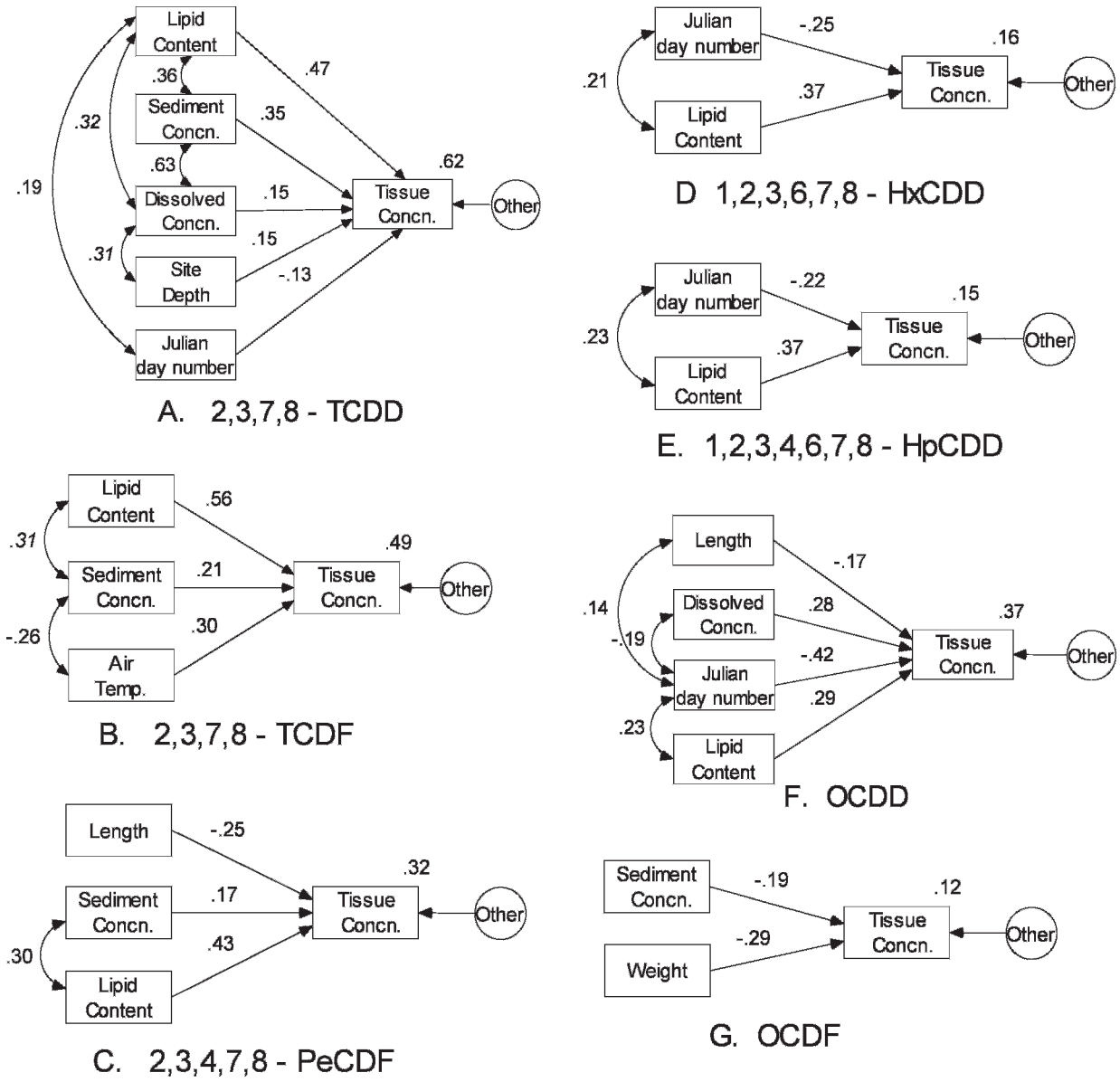

Fig. 5. Structural equation models of bioaccumulation of selected polychlorinated dibenzo-*p*-dioxin and dibenzofuran (PCDD/F) congeners in hardhead catfish fillets (tissue). Double-headed arrows represent standardized covariances. Single-headed arrows represent standardized model regression weights. The squared multiple correlation (just above and to the right of the tissue box) is the fraction of the variance in tissue concentrations explained by the model. (**A**) 2,3,7,8-tetrachlorodibenzo-*p*-dioxin (TCDD); (**B**) 2,3,7,8-tetrachlorodibenzofuran (TCDF); (**C**) 2,3,4,7,8-pentachlorodibenzofuran (PeCDF); (**D**) 1,2,3,6,7,8-hexachlorodibenzo-*p*-dioxin (HxCDD); (**E**) 1,2,3,4,6,7,8-heptachlorodibenzo-*p*-dioxin (HpCDD); (**F**) octachlorodibenzo-*p*-dioxin (OCDD); (**G**) octachlorodibenzofuran (OCDF).

lipid content were positively related to Julian day number, indicating that HH became longer and fatter over the course of the year. Thus, it may be that the association between tissue concentration and day number resulted from growth dilution [22] or a shift to less contaminated prey. Note that lipid levels covaried with sediment and dissolved concentrations, which seems to indicate that fatter fish live in the more contaminated areas, which are also probably in the more productive, less salty waters.

It is important to note that while other explanatory variables do not appear in the SEM, this indicates not a lack of covariance with tissue concentrations but rather a covariation with the tissue concentrations that was not statistically significant after accounting for their covariation with other independent predictors in the model. Thus, it was rare for more than one strongly covarying factor (e.g., day number and air temperature or length and weight) to show up as significant in the SEM.

The SEM illustrated in Figure 5B explained 49% of the variability in TCDF concentrations in HH. Lipid content appeared to exert the greatest influence on observed variations in tissue levels. Other significant relationships were observed with sediment concentrations and air temperature, an indicator of seasonality.

The SEM for 2,3,4,7,8-pentachlorodibenzofuran in HH (Fig. 5C) explained only 32% of observed variability in tissue concentrations. As with TCDD and TCDF, lipid content and sediment concentrations were significant predictors of levels in tissue. The SEM also indicated that organism size in HH, as indicated by length, was inversely related to tissue levels.

The SEMs for 1,2,3,6,7,8-hexachlorodibenzo-*p*-dioxin (Fig. 5D) and 1,2,3,4,6,7,8-heptachlorodibenzo-*p*-dioxin (Fig. 5E)

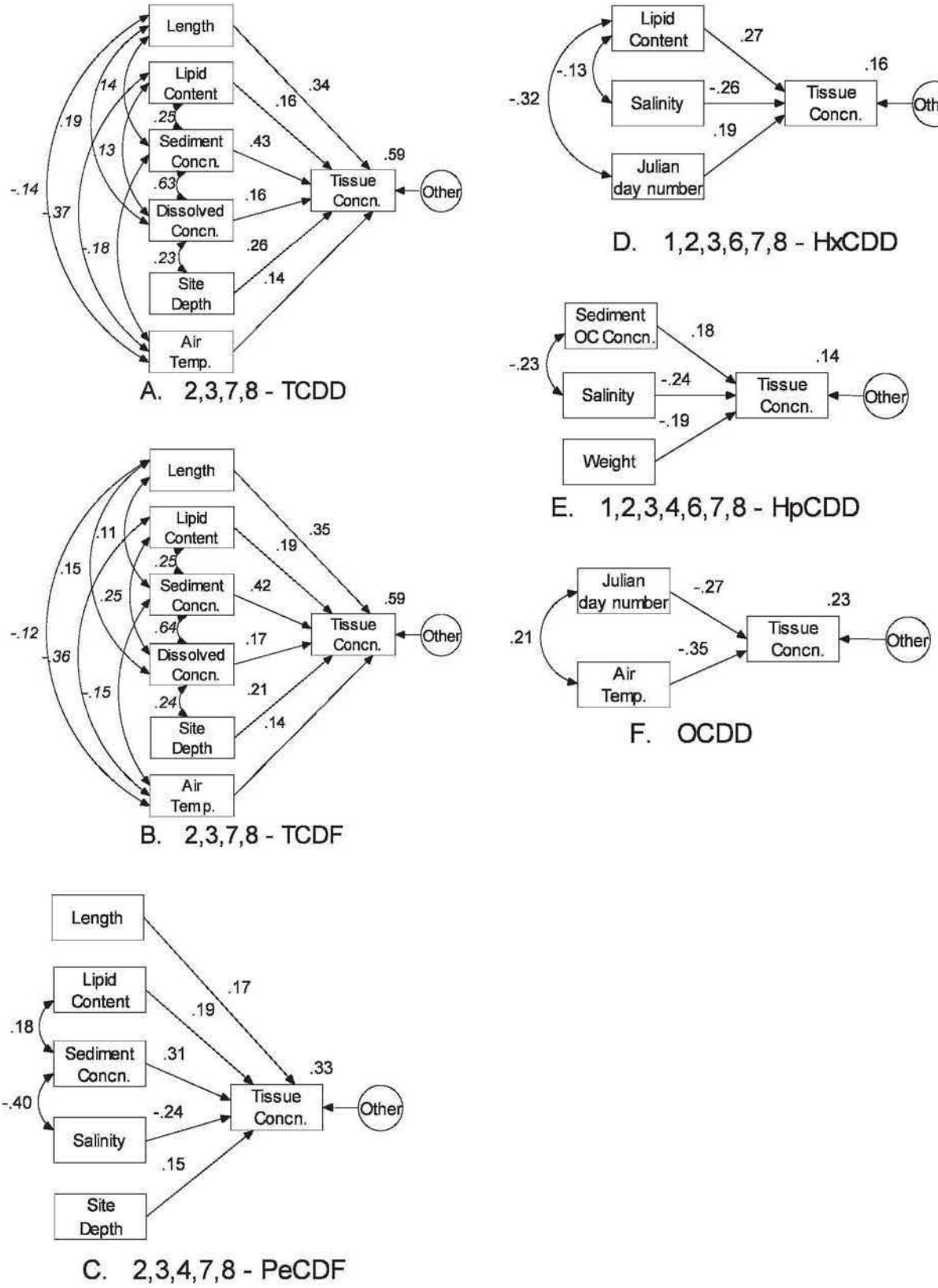

Fig. 6. Structural equation models of bioaccumulation of selected polychlorinated dibenzo-*p*-dioxin and dibenzofuran (PCDD/F) congeners in blue crab tissue. Double-headed arrows represent standardized covariances. Single-headed arrows represent standardized model regression weights. The squared multiple correlation (just above and to the right of the tissue box) is the fraction of the variance in tissue concentrations explained by the model. (**A**) 2,3,7,8-tetrachlorodibenzo-*p*-dioxin (TCDD); (**B**) 2,3,7,8-tetrachlorodibenzofuran (TCDF); (**C**) 2,3,4,7,8-pentachlorodibenzofuran (PeCDF); (**D**) 1,2,3,6,7,8-hexachlorodibenzo-*p*-dioxin (HxCDD); (**E**) 1,2,3,4,6,7,8-heptachlorodibenzo-*p*-dioxin (HpCDD); (**F**) octachlorodibenzo-*p*-dioxin (OCDD).

in HH were simple and explained less than 20% of the variance in the tissue concentrations. Only lipid content and Julian day number were significantly related to HH tissue concentrations. The limited ability of these SEMs to explain variations in tissue concentrations of pentachlorodibenzofuran indicates that other factors, such as metabolism, controlled the levels in tissues.

The SEM for OCDD (Fig. 5F) explained 37% of the observed variance in tissue concentrations in HH. As with all other PCDDs in HH, lipid content and day number were significantly related to tissue concentrations. Day number was the strongest predictor of tissue concentrations, with a standardized regression coefficient of −0.42. The dissolved OCDD concentration, but not the concentration in sediment, was also significantly related to tissue concentration in this model. Finally, fish length was inversely related to tissue concentration, which may provide some support for the hypothesized impact of growth dilution or a shift to less contaminated prey species.

The SEM for OCDF in HH (Fig. 5G) explained only 12% of the variability in observed tissue concentrations. In addition to sediment concentrations, fish weight was a significant (inverse) predictor of tissue concentrations.

Blue crab. The SEM for TCDD in BCs (Fig. 6A) explained 59% of the variability in observed tissue concentrations. As seen in HH, both sediment and dissolved phase TCDD concentrations were significantly related to tissue concentrations, with sediments exhibiting the much stronger relationship by a factor greater than two. Also similar to HH, BC tissue concentrations were significantly related to the total water depth at the sampling site and lipid content. In contrast to HH, tissue concentrations of TCDD in BC were only weakly related to lipid content. The length or, more accurately, width of the BC carapace was significantly related to tissue levels, with larger BC having higher levels of TCDD.

The SEM for TCDF in BC also explained 59% of the variability in tissue concentrations (Fig. 6B). This SEM exhibited pronounced similarity to that for TCDD, implying that the processes controlling bioaccumulation are similar. However, note that this SEM for BC was very different from that for HH. The SEM for 2,3,4,7,8-pentachlorodibenzofuran in BC (Fig. 6C) was also similar to those for TCDD and TCDF but explained only 33% of the variance in tissue concentrations. Air temperature and dissolved phase concentrations were not significant predictors of tissue concentrations, but salinity emerged as a significant inverse predictor.

The SEMs for 1,2,3,6,7,8-hexachlorodibenzo-*p*-dioxin and 1,2,3,4,6,7,8-heptachlorodibenzo-*p*-dioxin in BC tissue (Fig. 6D and E) account for less than 20% of the observed variance in tissue concentrations. Salinity was expected to be inversely related to tissue concentrations because the most contaminated areas were in less saline waters. Alternatively, the inverse relationship with salinity may reflect the inclusion of female crabs in the higher-salinity waters. Female crabs are reported to spend part of the year spawning in the Gulf of Mexico [24] and thus would be less exposed to PCDD/F contamination. However, these relationships explained little of the variance in tissue concentrations.

The SEMs for OCDD in BC (Fig. 6F) explained only 23% of the variability in tissue concentrations; only two seasonal effects, air temperature and day number, exhibited statistically significant relationships with tissue concentrations. No predictor variables exhibited statistically significant relationships with OCDF levels in BC tissues.

CONCLUSIONS

As predicted by EqP theory, the important influences of chemical properties, chemical concentrations in water and sediment, and tissue lipid content were apparent in the bioaccumulation of PCDD/F congeners in HH and BC of the HSC system. However, a large percentage of the variation in bioaccumulation could not be explained by EqP theory, indicating the great complexity of the system. This was particularly true for the penta- to octa-chlorinated congeners. Bioaccumulation factors and BSAFs declined with degree of chlorination for PCDD congeners, which may reflect steric constraints on membrane permeation, low dietary uptake efficiency, or reduced bioavailability due to strong sorption to bed and suspended sediment and colloidal phases. An apparent reduction in BAFs and BSAFs with increased concentrations in the sediment and water phases may be explained by the variable exposure of mobile organisms along wide-ranging spatial and temporal gradients of chemical contamination.

For both BC and HH, tissue concentrations appeared to be related more closely to sediment than water concentrations. This implies that sediments are the more important route of exposure for PCDD/Fs. Remediation efforts focused on legacy sediment contamination may be most effective in reducing tissue burdens of PCDD/Fs.

Other factors also apparently affect the extent of bioaccumulation in this system. These may include seasonal factors related to the organisms' temperature preferences and reproductive behavior, seasonal recruitment, the mobility of the organisms together with spatially heterogeneous concentrations in sediment and water, and the size and age of individual organisms. It is important to evaluate the risks of contaminant bioaccumulation in light of the temporal and spatial variability of exposure, as well as the mobility and life history of the species. After considering known variables, a large pool of unexplained variance existed in the levels of bioaccumulation, particularly for the more chlorinated congeners. Some of this variation may be explained by analytical uncertainty; however, biotransformation may also be an important factor in controlling the levels of bioaccumulation.

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Figure 1 - Sampling Locations

Table 1 - Dioxin Concentrations in Sediments from the San Jacinto River (in ng/kg-dw)

STATION	DATE	TOC (%)	2,3,7,8-TCDD	1,2,3,7,8-PeCDD	1,2,3,4,7,8-HxCDD	1,2,3,6,7,8-HxCDD	1,2,3,7,8,9-HxCDD	1,2,3,4,6,7,8-HpCDD	OCDD	2,3,7,8-TCDF	1,2,3,7,8-PeCDF	2,3,4,7,8-PeCDF	1,2,3,4,7,8-HxCDF	1,2,3,6,7,8-HxCDF	2,3,4,6,7,8-HxCDF	1,2,3,7,8,9-HxCDF	1,2,3,4,6,7,8-HpCDF	1,2,3,4,7,8,9-HpCDF	OCDF	Total TEQ	Average TEQ	OC-normalized Total TEQ (ng/kg-oc)	Average OC-normalized TEQ (ng/kg-oc)
11193	08/08/02	0.54	69	< 0.91	0.4	< 1.2	1	34	1000	290	5.1	6.3	10	1.8	1.1	1.1	6	1.4	20	102.8	102.8	19,040	19,040
11200	09/03/02	0.49	< 0.25	< 0.67	0.24	< 1.2	< 0.59	13	880	< 0.17	< 0.51	< 0.27	< 0.52	< 0.27	< 0.42	< 0.51	0.99	< 0.4	2.5	1.1	1.2	229	248
11200	09/03/02	0.49	< 0.25	< 0.68	< 0.12	< 1.2	< 0.6	19	1300	< 0.17	< 0.51	< 0.27	< 0.53	< 0.27	< 0.42	< 0.51	< 0.2	1.6	5.6	1.3		266	
16622	09/03/02	0.26	< 0.25	< 0.67	0.3	< 1.2	< 0.59	11	390	< 0.26	< 0.51	< 0.29	< 0.53	< 0.27	< 0.42	< 0.51	1	< 0.4	3.3	1.0	1.0	373	373
11193	10/31/02	0.61	44	0.8	0.71	1.8	1.7	51	1500	160	3.9	4.1	4.9	1.9	0.81	0.62	6.4	0.84	32	64.4	64.4	10,563	10,563
11200	11/21/02	0.1	< 0.25	< 0.68	< 0.12	< 1.2	< 0.6	1.9	99	< 0.17	< 0.51	< 0.27	< 0.53	< 0.27	< 0.42	< 0.51	0.36	< 0.4	< 2.4	0.8	0.8	759	759
11193	05/13/03	0.84	94	< 0.67	0.53	1.2	1.5	42	1500	390	7.5	7.5	9.9	2.1	0.61	0.87	6.4	1.3	25	138.4	138.4	16,480	16,480
16622	05/29/03	1.28	0.55	< 0.63	1.7	4.3	4.4	150	6600	1.2	< 0.47	0.82	1.3	1.1	< 0.39	< 0.47	13	1.3	44	6.2	6.2	484	484
11193	03/24/04	1.66	61	2.3	< 2.1	< 3.6	5.5	160	5200	230	6.6	6.2	11	3.6	2.2	1.7	19	2.8	160	94.5	94.5	5,691	5,691
11197	03/24/04	0.48	5.9	0.72	< 0.61	1.7	< 1.4	67	2600	16	< 0.64	0.98	< 1.4	0.62	0.56	0.37	6	0.64	39	10.5	10.5	2,197	2,197
18388	08/02/04	0.9	10	0.87	1.6	4.1	3.6	140	4800	28	2	1.6	2.7	1.4	1.4	0.63	14	2.5	140	18.8	18.8	2,089	2,089
11193	08/11/04	1.52	11	0.46	0.45	0.89	1.1	31	1400	55	1	1.4	0.7	0.49	0.32	< 0.21	2.7	< 0.38	17	18.6	57.4	1,222	3,780
11193	08/11/04	1.52	60	1.9	2	4	5.2	170	7800	260	6	5.7	6.4	2.9	1.3	1	15	2.2	120	96.3		6,337	
18389	08/11/04	0.43	11	0.6	0.76	1.6	1.7	59	2100	33	< 0.2	1.2	1.8	0.77	0.55	0.36	5.6	0.68	56	17.3	17.3	4,027	4,027
11197	08/11/04	1.17	17	1.5	2.3	4.9	5.5	190	7300	53	2.6	2.4	4.5	2.9	1.4	0.89	15	2.1	100	31.1	30.4	2,661	2,600
11197	08/11/04	1.17	17	< 3.9	< 4.3	< 3.3	< 3	190	6800	52	< 2.8	< 2.5	< 2.6	< 2.3	< 2.8	< 2.4	11	< 3.4	110	29.7		2,539	
11193	11/04/04	0.807	31	0.84	0.7	1.5	1.9	57	2000	120	2.5	2.6	3.2	1.1	0.6	< 0.2	8.1	1	100	46.9	43.9	5,811	5,445
11193	11/04/04	0.807	27	0.62	0.73	1.9	2.2	71	2300	100	2.6	2.5	3.4	0.96	0.53	0.39	8	0.92	110	41.0		5,078	
11197	11/09/04	1.66	8.8	0.69	1.1	2.7	2.9	100	3800	26	1.1	1.2	2	0.71	0.82	< 0.27	9.2	1.1	72	15.8	15.8	951	951
7	08/15/05	0.645	9.7	0.38	0.54	1.1	1.3	33	1300	31	0.95	0.92	1.8	< 0.1	0.41	< 0.15	4.8	0.65	65	14.8	14.8	2,296	2,296
6	08/15/05	0.552	7.4	< 0.37	0.9	< 0.37	1.4	40	1500	24	0.83	0.8	1.3	0.64	< 0.21	< 0.32	4.7	0.6	35	11.6	11.6	2,107	2,107
13	08/17/05	0.872	8	0.3	0.42	0.94	1.2	26	730	29	2.5	1.3	2.8	0.97	< 0.092	0.63	3.6	0.57	33	12.9	12.9	1,479	1,479
17	08/17/05	0.832	21	0.55	0.81	1.9	2.3	66	2400	73	2.2	2	3.1	0.86	0.65	0.3	8.1	1.2	86	32.0	32.0	3,847	3,847
21	08/17/05	1.54	27	0.97	1.4	3.3	3.8	100	3900	94	3	2.8	4	1.3	1.1	0.78	10	1.4	68	42.2	42.2	2,738	2,738
5	08/17/05	0.72	6.8	0.41	0.81	1.5	1.6	52	1700	23	0.83	0.86	1.3	0.43	0.42	0.26	5.7	0.68	54	11.5	11.5	1,602	1,602
4	08/17/05	0.562	8.1	0.35	0.56	1.4	1.7	46	1800	28	0.98	0.87	1.4	0.8	0.38	0.27	4.7	0.68	41	13.3	14.9	2,359	2,472
4-DUP	08/17/05	0.636	10	0.48	0.84	1.6	2	56	2000	35	1.3	1.1	2.6	0.78	0.61	< 0.15	6	0.93	51	16.4		2,586	
18	08/17/05	1.02	25	0.97	1.7	3.8	4	120	3700	63	5.1	3.6	4.7	2.8	1.6	2.6	19	3.1	310	38.2	38.2	3,750	3,750
19	08/17/05	0.48	13	0.38	0.76	1.7	1.9	62	2700	41	1.8	1.4	2.3	0.75	0.51	0.41	6.8	0.96	58	20.3	20.3	4,232	4,232
1	08/17/05	1.56	54	1.1	1.2	3	3.2	83	2800	200	5.1	4.5	5.1	2.4	1.2	0.93	8.2	1.6	58	80.1	80.1	5,134	5,134
2	08/17/05	1.37	45	0.94	1.5	3	3.7	96	3600	150	4.8	4	5.8	2	1.1	0.92	9.9	1.7	63	66.3	66.3	4,837	4,837
16	08/18/05	0.528	89	1.1	< 0.11	0.79	0.86	21	590	440	7.6	7.3	7.2	2.3	0.66	0.91	2.9	0.95	8.7	138.2	138.2	26,179	26,179
8	08/18/05	0.884	20	0.59	0.78	1.9	2.2	58	2000	71	2.1	1.9	3	1.1	0.61	0.56	7.3	1.3	90	30.6	30.6	3,465	3,465
9	08/18/05	1.19	7.8	0.49	0.76	1.3	1.8	58	2900	25	0.99	0.84	1.4	< 0.12	0.38	0.3	4.3	0.54	36	13.2	13.2	1,108	1,108
20	08/18/05	0.15	1.2	< 0.082	0.15	0.28	0.33	8.8	330	3.8	0.2	0.14	0.25	0.12	0.13	< 0.069	0.85	< 0.14	6.6	2.0	2.0	1,331	1,331
3	08/18/05	1.24	19	0.59	1	2.3	2.7	77	3200	63	2	1.8	2.7	0.92	0.69	0.27	8.6	1.3	93	29.4	29.4	2,371	2,371
15	08/18/05	10.7	21000	240	3.5	8.2	< 4.5	95	1200	82000	2800	2200	3900	1100	210	410	1100	440	390	30764	32396	287,516	307,353
15-DUP	08/18/05	10.4	23000	290	< 3.5	8.1	< 4.5	90	1200	93000	2900	2300	4600	1200	210	390	1300	520	450	34028		327,190	
14	08/18/05	0.351	24	0.34	0.19	< 0.098	0.43	13	450	85	2.5	2	3.4	0.92	0.27	0.33	2	0.55	7.5	34.4	34.4	9,791	9,791
11	08/18/05	0.83	360	3.7	1.1	2	1.8	75	2700	1400	35	30	47	13	2.7	4.7	18	5.3	65	522.8	547.6	62,987	65,774
11-DUP	08/18/05	0.835	390	3.9	1.1	2.7	2.6	90	2300	1600	36	31	40	11	2.5	4.3	14	4.3	47	572.5		68,561	
10	08/30/05	0.961	110	< 0.25	0.96	2.3	2.4	68	2700	380	11	9.2	15	3.5	1.1	1.8	11	2.3	89	155.6	155.6	16,188	16,188
12	08/30/05	1.64	35	0.92	6.2	15	5.3	1300	11000	130	3.9	3.7	6	2.4	1.7	0.9	52	3.8	390	70.9	70.9	4,321	4,321
11193	08/11/11	0.29	45	1.3	1.3	2.6	3.5	120	4200	210	4.2	4.1	7.8	2.5	1.3	< 1.1	13	1.4	170	73.3	73.3	25,264	25,264
11197	06/25/12	0.36	6	0.36	0.64	1.3	1.8	57	25	23	0.81	0.79	0.93	0.48	0.39	0.26	4.9	0.56	47	10.1	10.1	2,819	2,819
15301	08/20/12	0.23	3.9	0.17	0.36	0.76	0.87	25	77	1	0.35	0	0.45	0.27	< 0.29	0.15	5.6	0.35	67	4.8	4.8	2,102	2,102

Values reported to the detection limit

For TEQ calculations, non-detects assumed as 1/2 MDL.

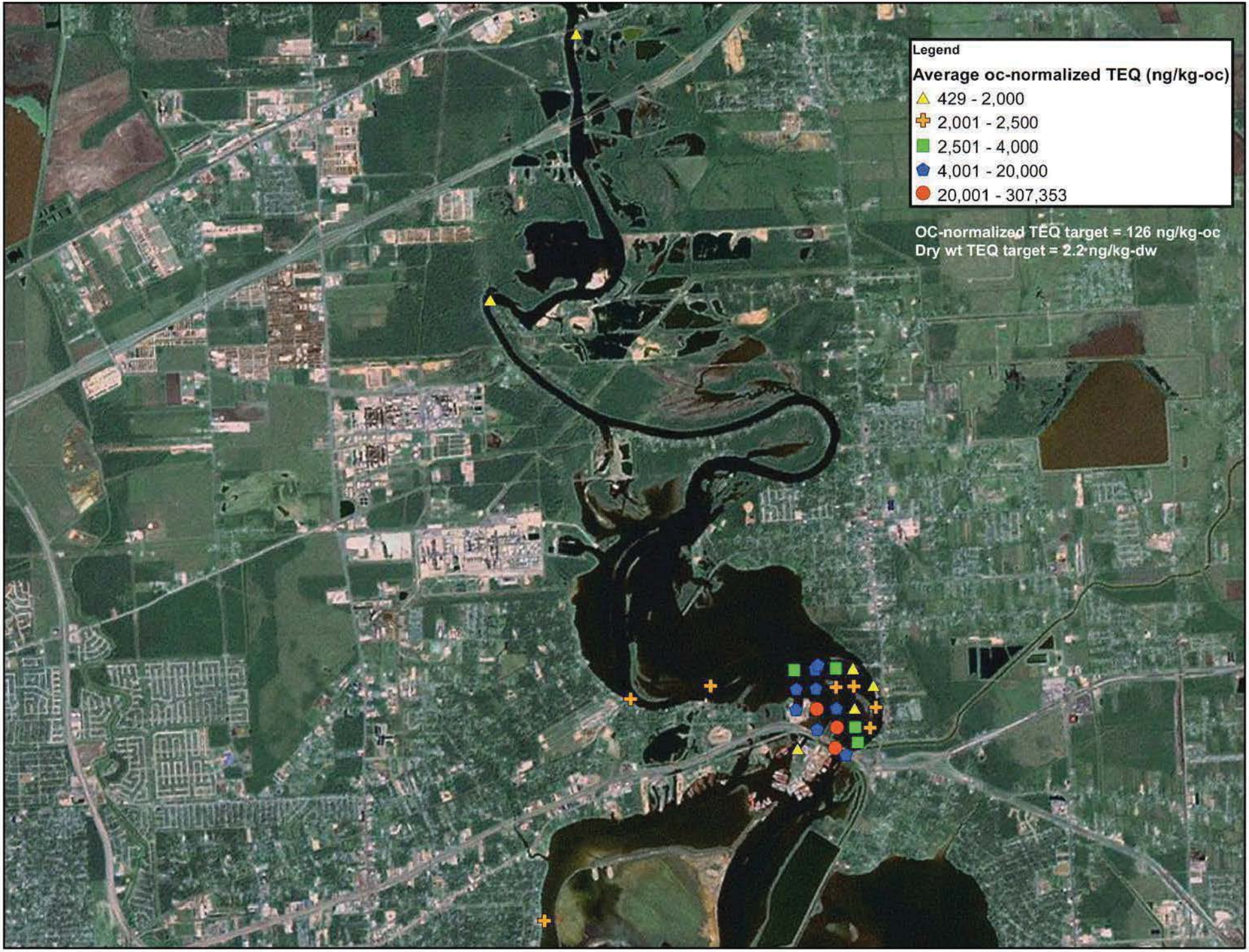


Figure 2 - Average Dioxin Concentrations in Sediment Samples from the SJR (2002-2012)

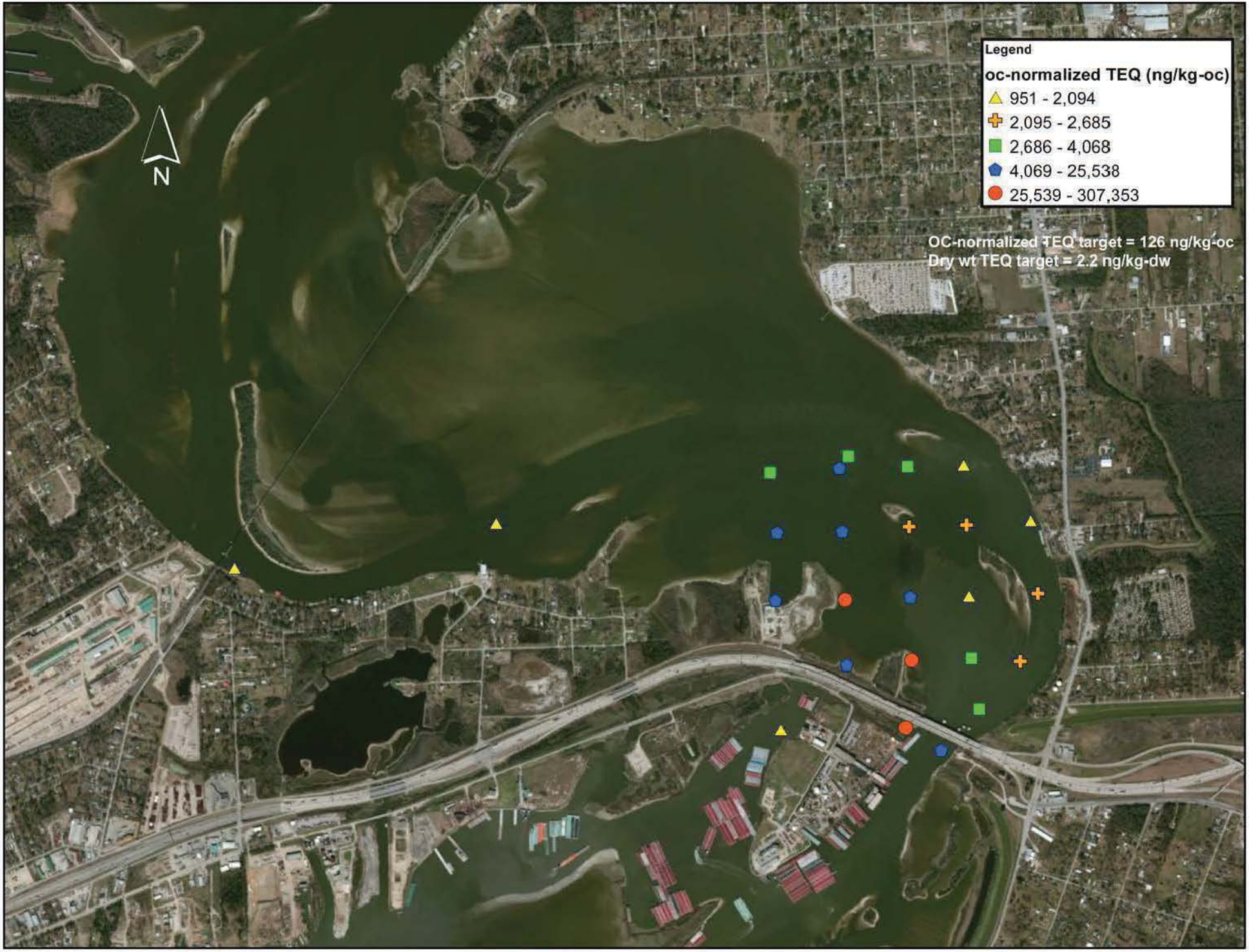


Figure 3 - Dioxin Concentrations in Sediment Samples from the SJR (Fall 2004 and Summer 2005)

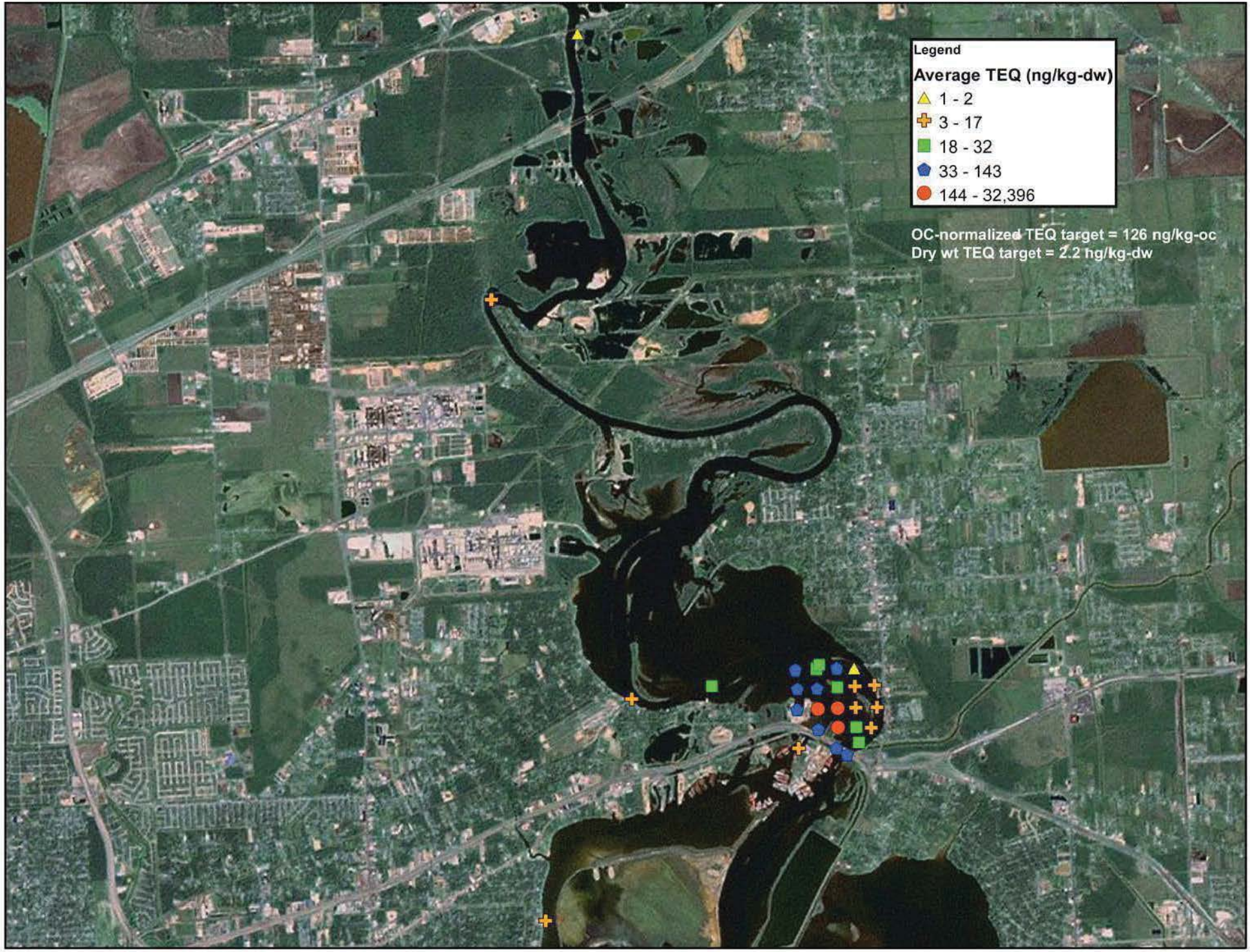


Figure 4 - Average Dioxin Concentrations in Sediment Samples from the SJR (2002-2012)

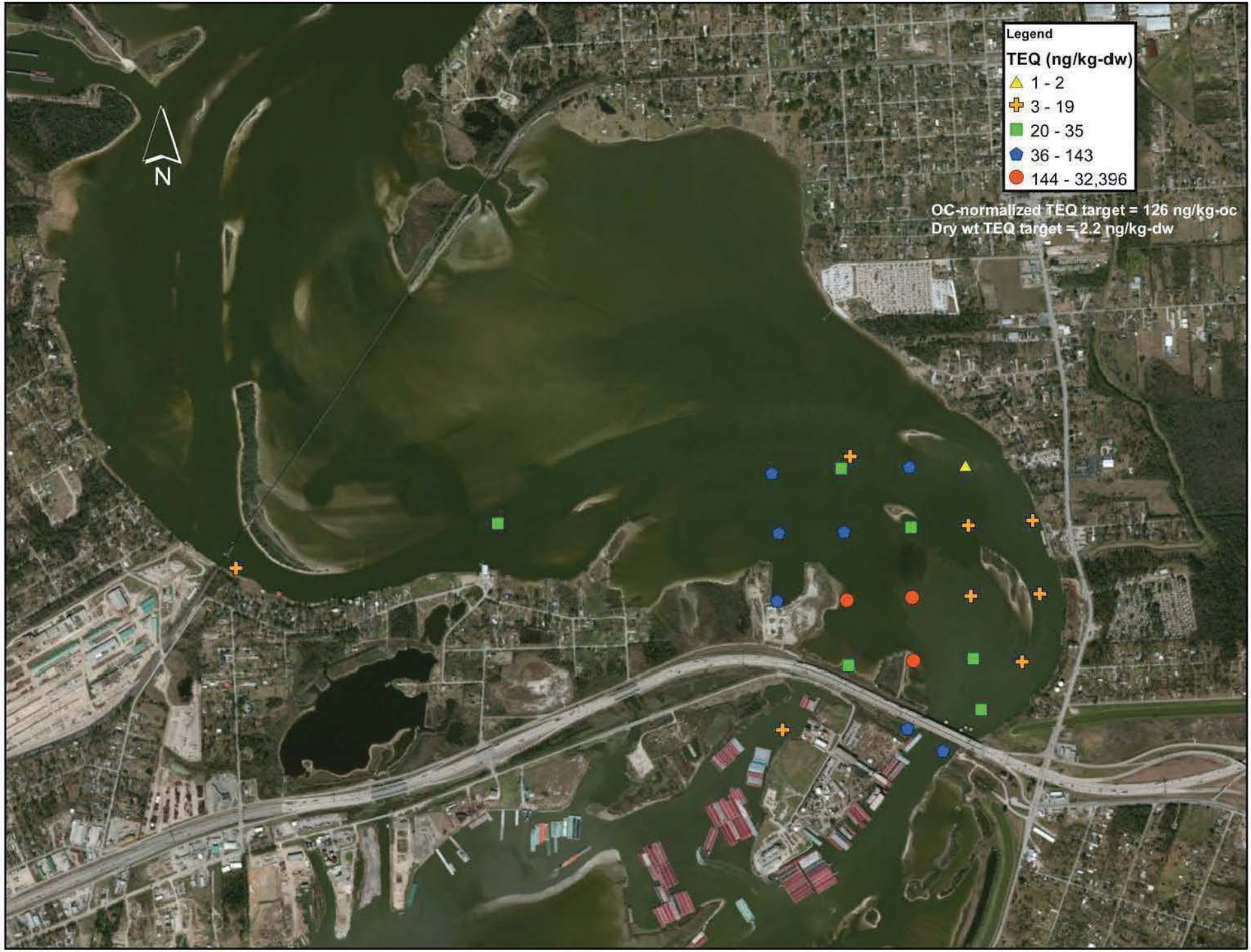
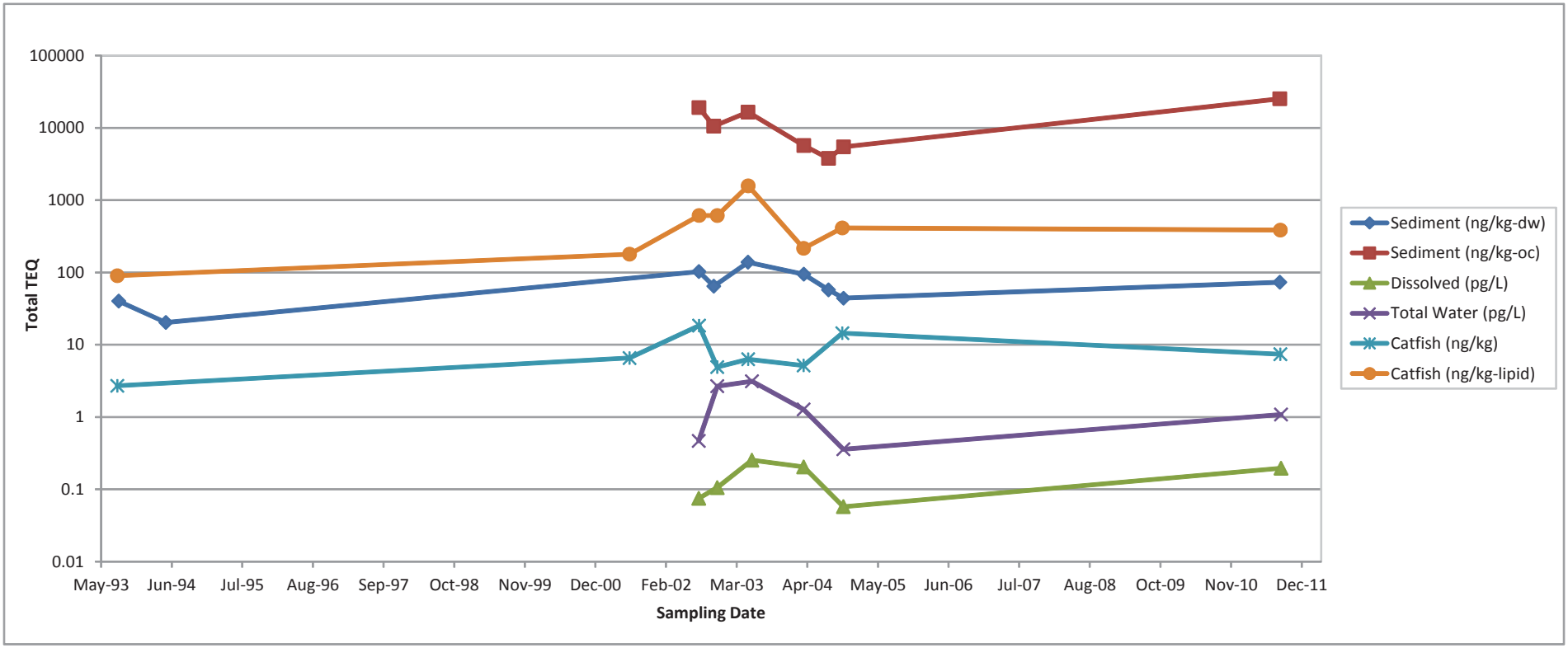
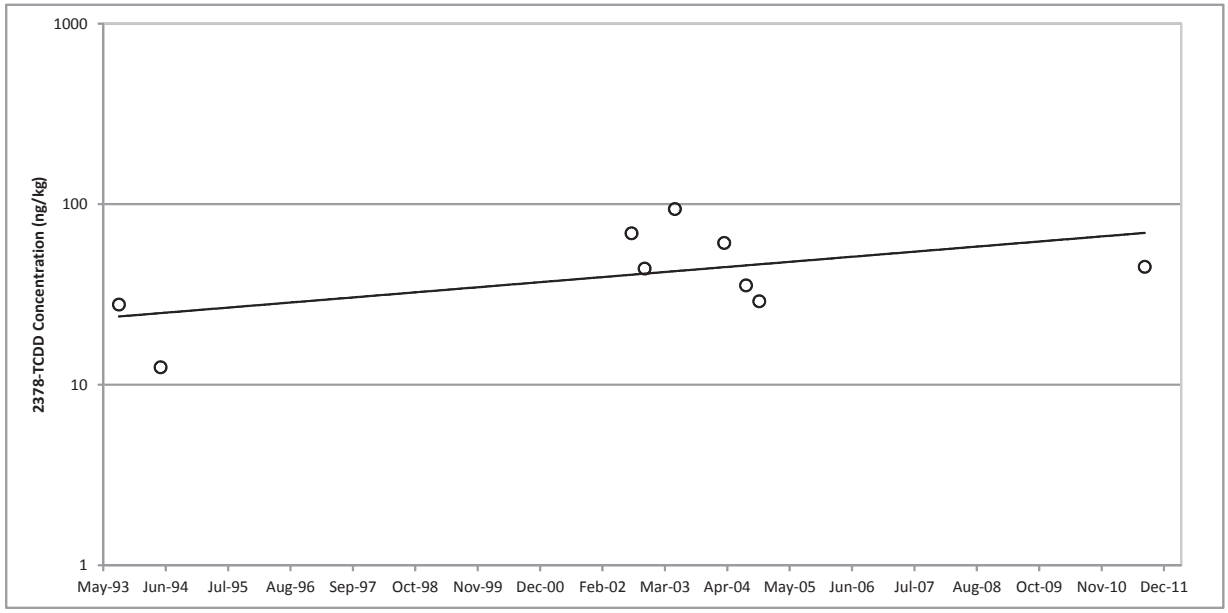


Figure 5 - Dioxin Concentrations in Sediment Samples from the SJR (Fall 2004 and Summer 2005)



Lines are drawn to facilitate visualization only and do not imply continuity.

Figure 6 - Time Series of Dioxin Concentrations in San Jacinto River at I-10 (Station 11193)



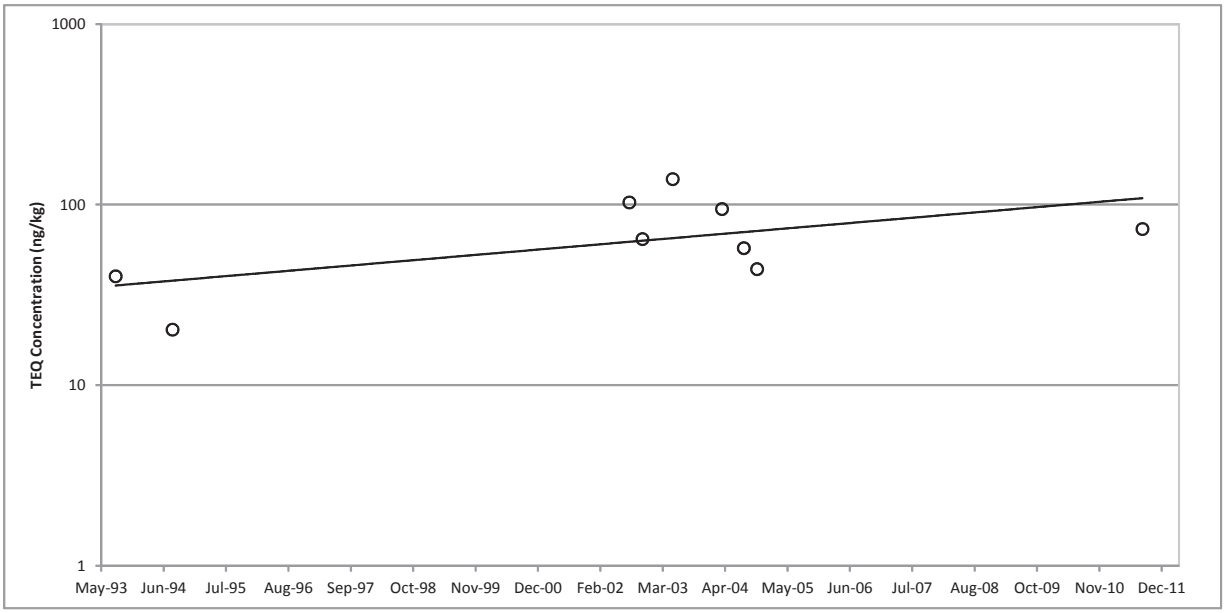


Figure 7 - Long Term Trend of Dioxin Concentrations in Sediments from the San Jacinto River (Station 11193)

Adopted June 30-2010 TCEQ

§§307.1 - 307.10

STATUTORY AUTHORITY

These amendments are adopted under the Texas Water Code, §26.023, that provides the Texas Commission on Environmental Quality with the authority to make rules setting Texas Surface Water Quality Standards (TSWQS) for all waters in the state. These amendments are also being adopted under Texas Water Code, §5.103, that authorizes the commission to adopt any rules necessary to carry out its powers and duties under the Texas Water Code and other laws of this state. The adopted amendments will satisfy the provision in Federal Clean Water Act, §303(c) that requires states to adopt water quality standards and to review and revise standards from time to time, but at least once each three year period. The revisions to the TSWQS are adopted to incorporate new information and studies on the appropriate uses and criteria of individual water bodies, to incorporate new scientific data on the effects of specific chemicals and pollutants, and to address new provisions in the Texas Water Code, federal regulations, and guidance of the EPA.

These amendments implement the Texas Water Code, §§5.103, 26.003, 26.023, and 26.026 in addition to Federal Clean Water Act, §303(c). No other codes or statutes will be affected by this adoption.

§307.1. General Policy Statement.

It is the policy of this state and the purpose of this chapter to maintain the quality of water in the state consistent with public health and enjoyment, propagation and protection of terrestrial and aquatic life, operation of existing industries, and taking into consideration economic development of the state; to

(G) bioavailability of specific toxic substances of concern, as determined by WER tests or other analyses approved by the commission; and

(H) new information concerning the toxicity of a particular substance.

(d) Specific numerical human health criteria.

(1) Numerical human health criteria are established in Table 2 of this paragraph.

Figure: 30 TAC §307.6(d)(1)

TABLE 2
Criteria in Water for Specific Toxic Materials
HUMAN HEALTH PROTECTION
(All values are listed or calculated in micrograms per liter unless otherwise noted)

		A	B
COMPOUND	CASRN	Water and Fish µg/L	Fish Only µg/L
Acrylonitrile	107-13-1	0.80	3.8
Aldrin	309-00-2	0.00094	0.0010
Anthracene	120-12-7	5,569	--
Antimony	7440-36-0	6*	1,071
Arsenic (d)	7440-38-2	10*	---
Barium (d)	7440-39-3	2,000*	---
Benzene	71-43-2	5*	513
Benzidine	92-87-5	0.00086	0.0020

Benzo(*a*)anthracene	56-55-3	0.068	0.33
Benzo(*a*)pyrene	50-32-8	0.068	0.33
Bis(chloromethyl)ether	542-88-1	0.0024	0.44
Bis(2-chloroethyl)ether	111-44-4	0.3	5.27
Bis(2-ethylhexyl)phthalate	117-81-7	6*	41
Bromodichloromethane	75-27-4	10.2	322
Bromoform	75-25-2	69.1	2,175
Cadmium (d)	7440-43-9	5*	---
Carbon Tetrachloride	56-23-5	4.1	29
Chlordane	12789-03-6	0.0080	0.0081
Chlorobenzene	108-90-7	100*	5,201
Chlorodibromomethane	124-48-1	7.6	239
Chloroform	67-66-3	70*	7,143
Chromium (Hex) (d)	18540-29-9	62	502
Chrysene	218-01-9	68.13	327
Cresols	1319-77-3§	736	1,981
Cyanide (free)#	57-12-5	200*	---
4,4' - DDD ‡, ††	72-54-8	166.16 ug/kg	166.16 ug/kg
4,4' - DDE ‡, ††	72-55-9	214.4 ug/kg	214.4 ug/kg
4,4' - DDT ‡, ††	50-29-3	209.04 ug/kg	209.04 ug/kg
2,4 - D	94-75-7	70*	---
Danitol	39515-41-8	5.39	5.44
1,2 - Dibromoethane	106-93-4	0.16	2.13
m-Dichlorobenzene	541-73-1	473	1,445
o-Dichlorobenzene	95-50-1	600*	4,336
p-Dichlorobenzene	106-46-7	75*	---
3,3'-Dichlorobenzidine	91-94-1	0.32	0.44
1,2 - Dichloroethane	107-06-2	5*	553
1,1 - Dichloroethylene	75-35-4	7*	23,916
Dichloromethane	75-09-2	5*	5,926
1,2-Dichloropropane	78-87-5	5*	226
1,3 - Dichloropropene	542-75-6	3.4	211
Dicofol	115-32-2	0.076	0.076
Dieldrin†	60-57-1	0.0005	0.0005
2,4-Dimethylphenol	105-67-9	257	571
Di-*n*-Butyl Phthalate	84-74-2	1,318	3,010
Dioxins/Furans +, †† (TCDD Equivalents)	1746-01-6	4.0E-04 ug/kg	4.0E-04 ug/kg

Congener/Isomer	Toxic Equivalency Factors
2,3,7,8 TCDD	1
1,2,3,7,8 PeCDD	1
2,3,7,8 HxCDDs	0.1
1,2,3,4,6,7,8 HpCDD	0.01

2,3,7,8 TCDF		0.1	
1,2,3,7,8 PeCDF		0.03	
2,3,4,7,8 PeCDF		0.3	
2,3,7,8 HxCDFs		0.1	
2,3,4,7,8 HpCDFs		0.01	
OCDD		0.0003	
OCDF		0.0003	
PCB 77		0.0001	
PCB 81		0.0003	
PCB 126		0.1	
PCB 169		0.03	
Endrin	72-20-8	0.20	0.20
Ethylbenzene	100-41-4	700*	7,143
Fluoride	16984-48-8	4,000*	---
Heptachlor	76-44-8	0.0015	0.0015
Heptachlor Epoxide	1024-57-3	0.00074	0.00075
Hexachlorobenzene	118-74-1	0.0044	0.0045
Hexachlorobutadiene	87-68-3	6.5	274
Hexachlorocyclohexane *(alpha)*	319-84-6	0.050	0.093
Hexachlorocyclohexane *(beta)*	319-85-7	0.17	0.33
Hexachlorocyclohexane *(gamma)* (Lindane)	58-89-9	0.2*	6.2
Hexachlorocyclopentadiene	77-47-4	50*	--
Hexachloroethane	67-72-1	27	62
Hexachlorophene	70-30-4	0.0080	0.0080
Lead (d)	7439-92-1	1.15	3.83
Mercury †, ††	7439-97-6	700 ug/kg	700 ug/kg
Methoxychlor	72-43-5	0.33	0.33
Methyl Ethyl Ketone	78-93-3	13,932	1.50E+6
Nickel (d)	7440-02-0	332	1140
Nitrate-Nitrogen as total Nitrogen	14797-55-8	10,000*	---
Nitrobenzene	98-95-3	11	463
N-Nitrosodiethylamine	55-18-5	0.0037	2.1
N-Nitroso-di-*n*-Butylamine	924-16-3	0.119	4.2
Pentachlorobenzene	608-93-5	1.0	1.0
Pentachlorophenol	87-86-5	1.0*	57
Polychlorinated Biphenyls *(PCBs)* ±, **, ††	1336-36-3	19.96 ug/kg	19.96 ug/kg
Pyridine	110-86-1	23	2,014
Selenium	7782-49-2	50*	---
1,2,4,5 - Tetrachlorobenzene	95-94-3	0.65	0.71
1,1,2,2-Tetrachloroethane	79-34-5	3.2	76
Tetrachloroethylene	127-18-4	5*	49
Thallium	7440-28-0	0.75	1.50
Toluene	108-88-3	1,000*	---

Toxaphene	8001-35-2	0.0053	0.0053
2,4,5 - TP (Silvex)	93-72-1	7.3	7.6
1,1,1 - Trichloroethane	71-55-6	200*	956,663
1,1,2-Trichloroethane	79-00-5	5*	295
Trichloroethylene	79-01-6	5*	649
2,4,5 - Trichlorophenol	95-95-4	1,194	2,435
TTHM (Sum of total trihalomethanes)		80	---
bromodichloromethane	75-27-4		
dibromochloromethane	124-48-1		
tribromomethane (bromoform)	75-25-2		
trichloromethane (chloroform)	67-66-3		
Vinyl Chloride	75-01-4	0.25	24

* Based on Maximum Contaminant Levels (MCLs) specified in 30 TAC §290 (relating to Public Drinking Water).

† An assumed BCF of 33,000 is used to translate the tissue-based criterion to a water column criterion for the purposes of evaluating TPDES permittees. The criterion to protect combined water and fish consumption can not exceed drinking water MCL of 2 µg/L. BCF value taken from *Water Quality Criteria for the Protection of Human Health: Methylmercury*; January 2001; EPA 823-R-01-001.

§ Consists of *m*, *o*, and *p* Cresols. The criteria are the same for all three, and the criteria are applied independently to each form of cresol. CASRNs for cresols are 95-48-7 for *o*-Cresol, 108-39-4 for *m*-Cresol, and 106-44-5 for *p*-Cresol.

‡ An assumed BCF of 53,600 is used to translate the tissue-based criterion to a water column criterion for the purposes of evaluating TPDES permittees. BCF value taken from *Ambient Water Quality Criteria for DDT*; October 1980; EPA 440/5-80-038.

\# Compliance is determined using the analytical method for available cyanide

\+ An assumed BCF of 5,000 is used to translate the tissue-based criterion to a water column criterion for the purposes of evaluating TPDES permittees. BCF value taken from *Ambient Water Quality Criteria for 2,3,7,8-Tetrachloro-dibenzo-p-dioxin*; February 1984; EPA 440/5-84-007.

(d) Indicates the criteria is for the dissolved fraction in water. All other criteria are for total recoverable concentrations.

± An assumed BCF of 31,200 is used to translate the tissue-based criterion to a water column criterion for the purposes of evaluating TPDES permittees. BCF value taken from *Ambient Water Quality Criteria for Polychlorinated Biphenyls*; October 1980; EPA 440/5-80-068.

** Until Method 1668 or equivalent method to measure PCB congeners is approved in 40 Code of Federal Regulations Part 136, compliance with PCB criteria is determined using Arochlor data or any alternate method listed in a TCEQ-approved Quality Assurance Plan.

†† Based on fish tissue wet weight.

(2) Categories of human health criteria:

Remediation Sites with Dioxin as Contaminant

Project Name	State	Site Characteristics	Remedial Action	Sediment Concentration (ng/Kg)	Sediment Concentration Target (ng/Kg)
Olympic View Resource Area	WA	12.9 acre of intertidal, subtidal and upland areas	8,000 ton sand cap in subtidal area	0.0011 - 0.647	< 0.02
Passaic River, Phase 1	NJ	Tidally-influenced reach of the Passaic River. Highest dioxin concentrations between 2 and 12 ft sediment depth.	Mechanical dredging (200,000 cy)	average = 100 maximum = 5300	Based on sediment volume; not numerical criteria
Woonasquatucket River	RI	Allendale Pond, Lyman Mill Pond and the Lyman Mill Stream and floodplain and a forested wetland below the Allendale Dam.	Removal of sediment and placement in an upland confined disposal facility	1.5 - 14.8 0.094-8.2 1.0 - 20 with a maximum of 117 1.0 - 2.48	remove sediment with concentration greater than EPA limit of 1.0 ppb from residential / recreational properties
Love Canal	NY	Sediments in Bergoholtz, Cayuga, and Black Creeks	dry excavation and landfill (thermally destructed if over 10 ppb)	average 0.38 in creeks, 600 in sewer / storm water sediment	1.0
Koppers	NC	Soil in drainage ditches associated with the Ashley River	dry excavation & solidified capping	"trace"	1.5
McCormick and Baxter	CA	dead-end slough with some tidal influence	capping	"trace"	0.021 (unclear if fish tissue or sediment)

The following projects included dioxins as one of many CoCs

Fox River - Project 3 (OU 1)	WI	Little Lake Butte de Morts river reach flows from outlet of Lake Winnebago for 3 miles to Appleton.	370,500 cy dredged with 260 acres capped with armor stone and/or sand	no data	no data
Fox River - OU 2	WI	Meandering section of the river typically less than 1000 ft wide.	Monitored Natural recovery over 40 years.	no data	no data
Fox River - OU 4	WI	Depositional section of river underlain by deep silt and soft sediment up to 13 ft deep.	dredging of 5900000 cy of sediment with offsite disposal	no data	no data
Fox River - OU 5	WI	Comprised of 1000 square miles of Green Bay with a mean depth of 65 ft and a maximum depth of 176 ft.	Monitored Natural recovery over 40 years, with limited dredging	no data	no data

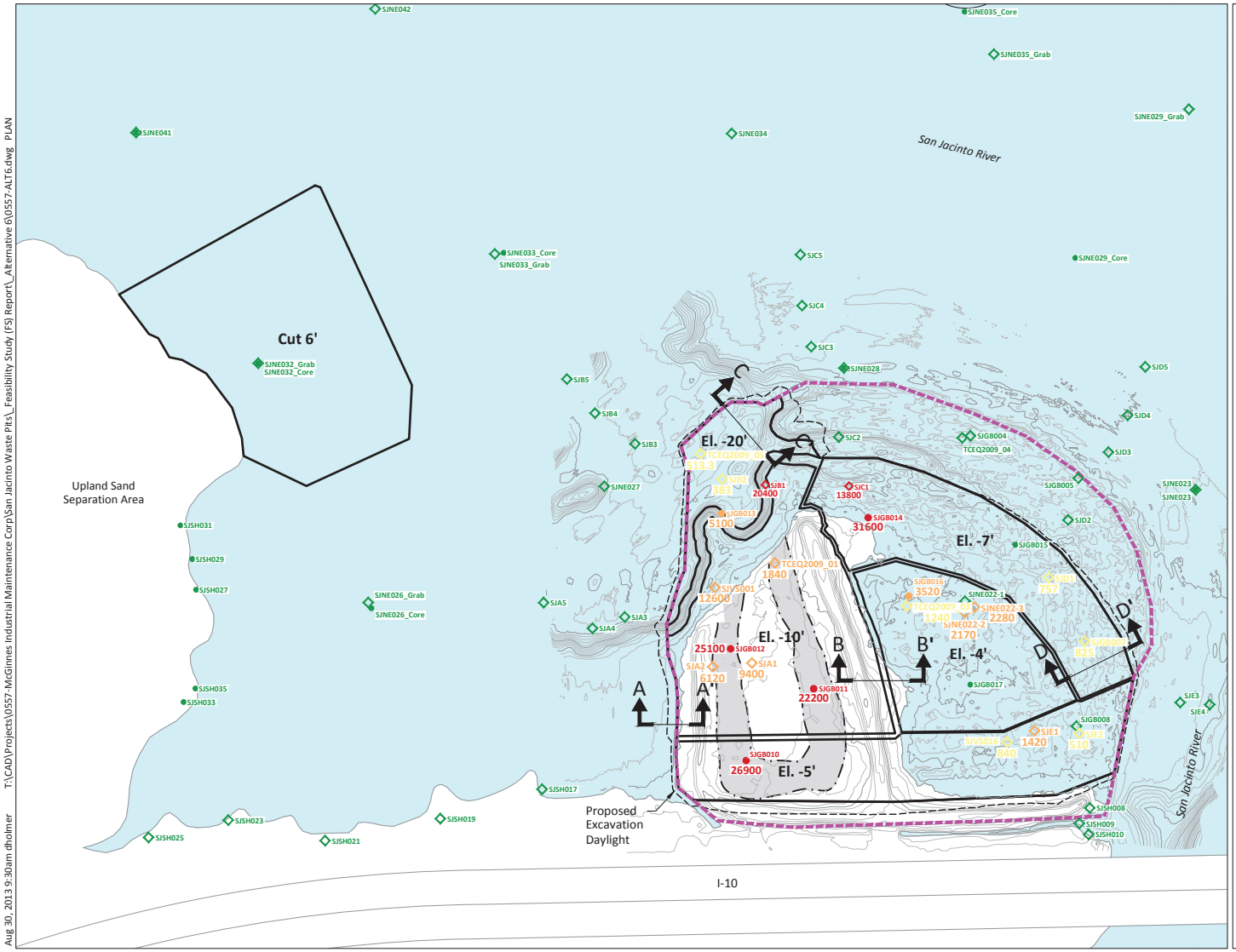
Remediation/Capping at other Superfund Sediment Sites

a. Onondaga Lake, NY
    i. In 2007 the Federal Court approved an agreement requiring Honeywell International Inc. (the successor to Allied-Signal Inc.) to remediate the contaminated sediments in the bottom of the lake. The plan involves dredging contaminated sediments, capping approximately 580 acres of lake bottom sediments, and restoring habitat. Under the direction of NYSDEC, Honeywell is currently working in cooperation with a team of scientists, engineers and federal, state and municipal leaders on designs for the restoration of the lake, including a dredging strategy, a sediment containment area and wastewater treatment. The plan calls for approximately 2 million cubic yards of sediments to be hydraulically dredged from the bottom of the lake and piped to a sediment consolidation area in Camillus, NY.
    http://www.dec.ny.gov/chemical/8668.html

b. Hudson River, NY
    i. Phase two requires the EPA and General Electric to dredge 2.4 million tons of sediment from the most polluted parts of the river, over a 40-mile stretch of the Hudson between Fort Edward and Troy. The long-delayed recovery is expected to take five to seven years.
    http://www.thirteen.org/metrofocus/2011/11/four-toxic-rivers-a-super-sad-true-superfund-story/

c. Lower Duwamish Waterway, Washington
    i. Proposed Plan for Cleanup:
    ii. For RAO 1 (Protection of human health via ingestion of seafood),
        1. Dioxin/Furan PRG was set at 2 ng TEQ/kg dw (natural background).
        2. Dredge or partial-dredge and cap approximately 84 acres of more highly contaminated sediments (see Section 10.2) where it is necessary to maintain water depth for human use or to maintain habitat. Approximately 790,000 cubic yards of dredged materials will be transported via truck or rail for disposal at a permitted upland off-site landfill facility.[13] If sediment contamination is 4 feet thick[14] or less in an area selected for dredging, all contaminated sediments will be dredged. If contamination is greater than 4 feet thick, sediments will be partially dredged and capped.

    http://yosemite.epa.gov/r10/cleanup.nsf/sites/lduwamish



LEGEND:

- Existing Contour (1 Foot Interval)
- El. -10 — Target Cut Elevation (NAVD 88)
- TCRA Cap Limit
- TCRA Footprint of Stabilization
- Area Below Mean Tide Level (0.83 Feet NAVD88)
- SJGB014 — Core location: TEQ ≥ 13,000 ng/kg
- SJGB013 — Core location: 1,300 ≤ TEQ < 13,000 ng/kg
- SJGB016 — Core location: 220 ≤ TEQ < 1,300 ng/kg
- SJGB017 — Core location: TEQ < 220 ng/kg
- SJB1 — Grab location: TEQ ≥ 13,000 ng/kg
- SJA1 — Grab location: 1,300 ≤ TEQ < 13,000 ng/kg
- SJB2 — Grab location: 220 ≤ TEQ < 1,300 ng/kg
- SJC3 — Grab location: TEQ < 220 ng/kg
- 825 — Concentration TEQ_{DF} (ng/kg dw) (See Note 1)
- A A' — Cross Section Location (See Figure 4-8)

NOTE:
1. Concentration shown at each sample location represents the highest concentration calculated at any depth interval at that location.

SOURCE: Drawing prepared from surveys provided by Hydrographic Consultants dated October 2012 and January/February 2013.
HORIZONTAL DATUM: Texas State Plane South Central, NAD83, U.S. Feet.
VERTICAL DATUM: NAVD 88.

0 200
Scale in Feet

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Figure 4-7
Plan View - Alternative 6, Full Removal
Feasibility Study
San Jacinto River Waste Pits Superfund Site

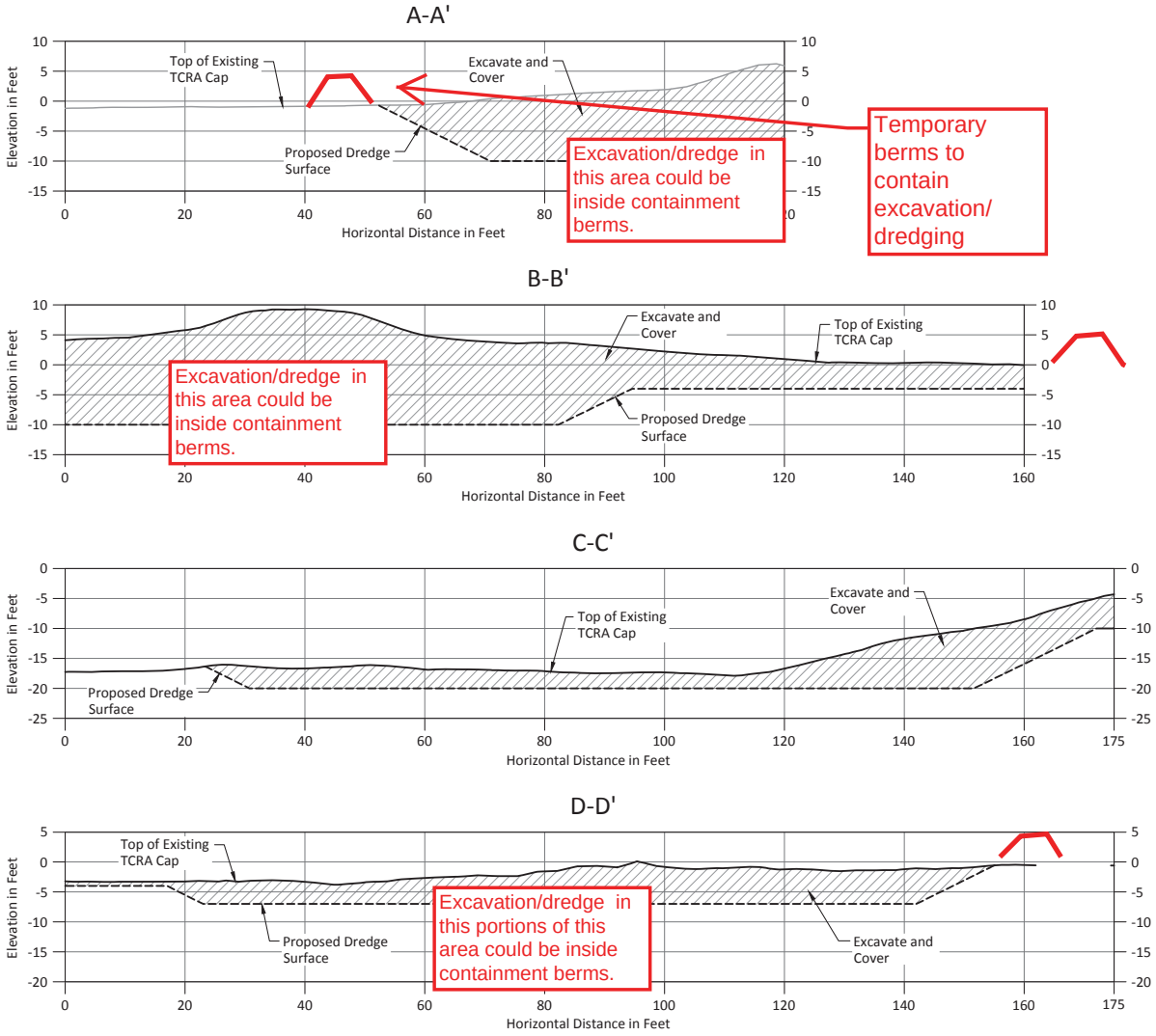
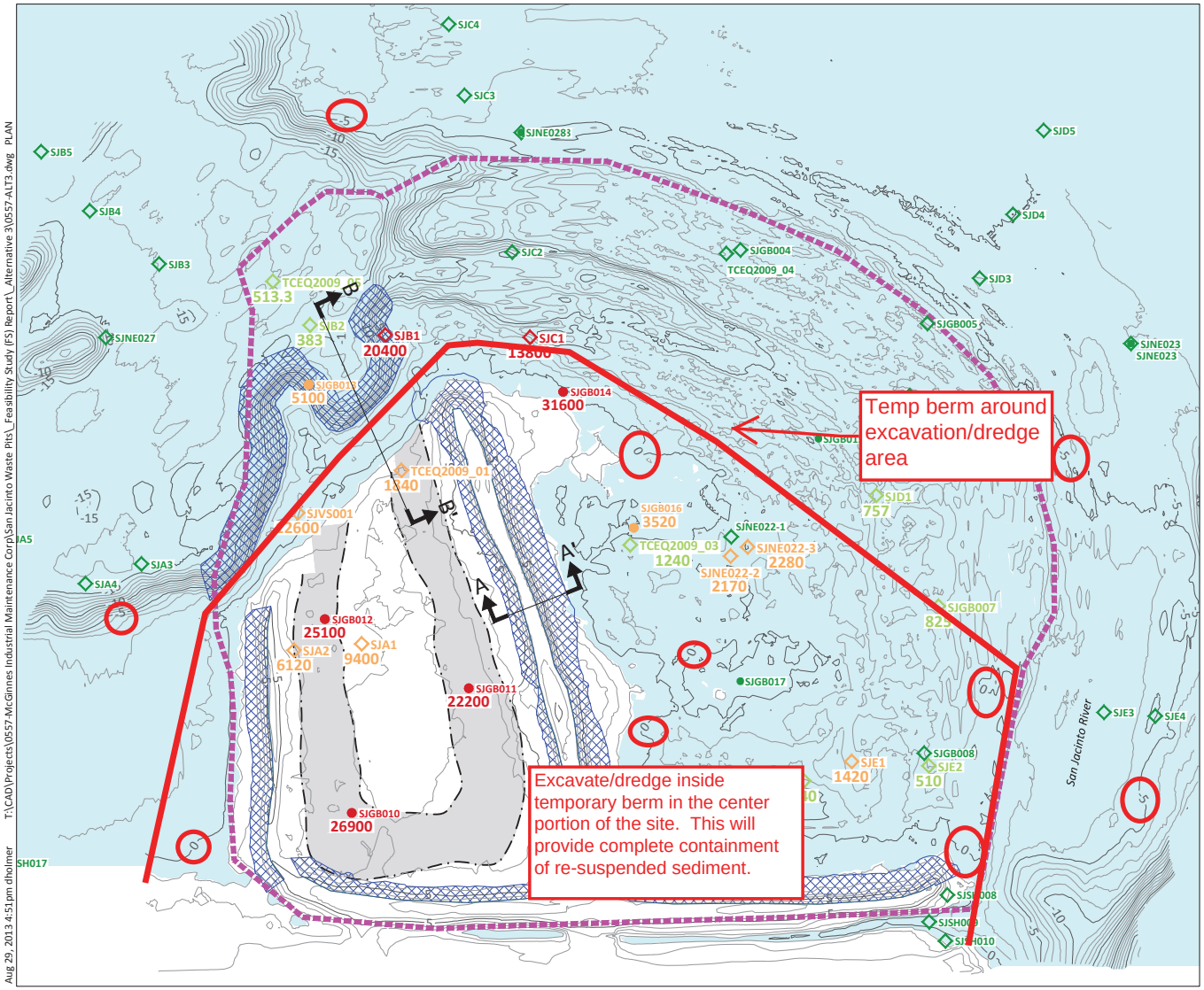


Figure 4-8
Cross Sections A-A', B-B', C-C', and D-D' - Alternative 6, Full Removal
Feasibility Study
San Jacinto River Waste Pits Superfund Site



LEGEND:

- Existing Contour (1 Foot Interval)
- TCRA Cap Limit
- Area of Additional Rock Placement for Flattening Slopes to 5H:1V on berms and 3H:1V in the Northwest Area
- Area Below Mean Tide Level (0.83 Feet NAVD88)
- TCRA Footprint of Stabilization
- SJGB014 Core location: TEQ ≥ 13,000 ng/kg
- SJGB013 Core location: 1,300 ≤ TEQ < 13,000 ng/kg
- SJGB016 Core location: 220 ≤ TEQ < 1,300 ng/kg
- SJGB017 Core location: TEQ < 220 ng/kg
- SJB1 Grab location: TEQ ≥ 13,000 ng/kg
- SJA1 Grab location: 1,300 ≤ TEQ < 13,000 ng/kg
- SJB2 Grab location: 220 ≤ TEQ < 1,300 ng/kg
- SJC3 Grab location: TEQ < 220 ng/kg
- 825 Concentration TEQ_{DF} (ng/kg dw) (See Note 1)
- A A' Cross Section Location (See Figure 4-2)

NOTE:
1. Concentration shown at each sample location represents the highest concentration calculated at any depth interval at that location.

SOURCE: Drawing prepared from surveys provided by Hydrographic Consultants dated October 2012 and January/February 2013.
HORIZONTAL DATUM: Texas State Plane South Central, NAD83, U.S. Feet.
VERTICAL DATUM: NAVD 88.

0 120
Scale in Feet

T:\CAD\Projects\0557-McGinnes Industrial Maintenance Corp\San Jacinto Waste Pits_Feasibility Study (FS) Report_Alternative 3\0557-ALT3.dwg PLAN
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Figure 4-1
Plan View - Alternative 3, Permanent Cap
Feasibility Study
San Jacinto River Waste Pits Superfund Site